Near Earth Asteroid Observation Program

Subcommittee on Disaster Reduction

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Planetary Science Division
NASA HQ
4 April 2013

Is this a Current Day Threat?

Meteor Crater
Winslow, Arizona

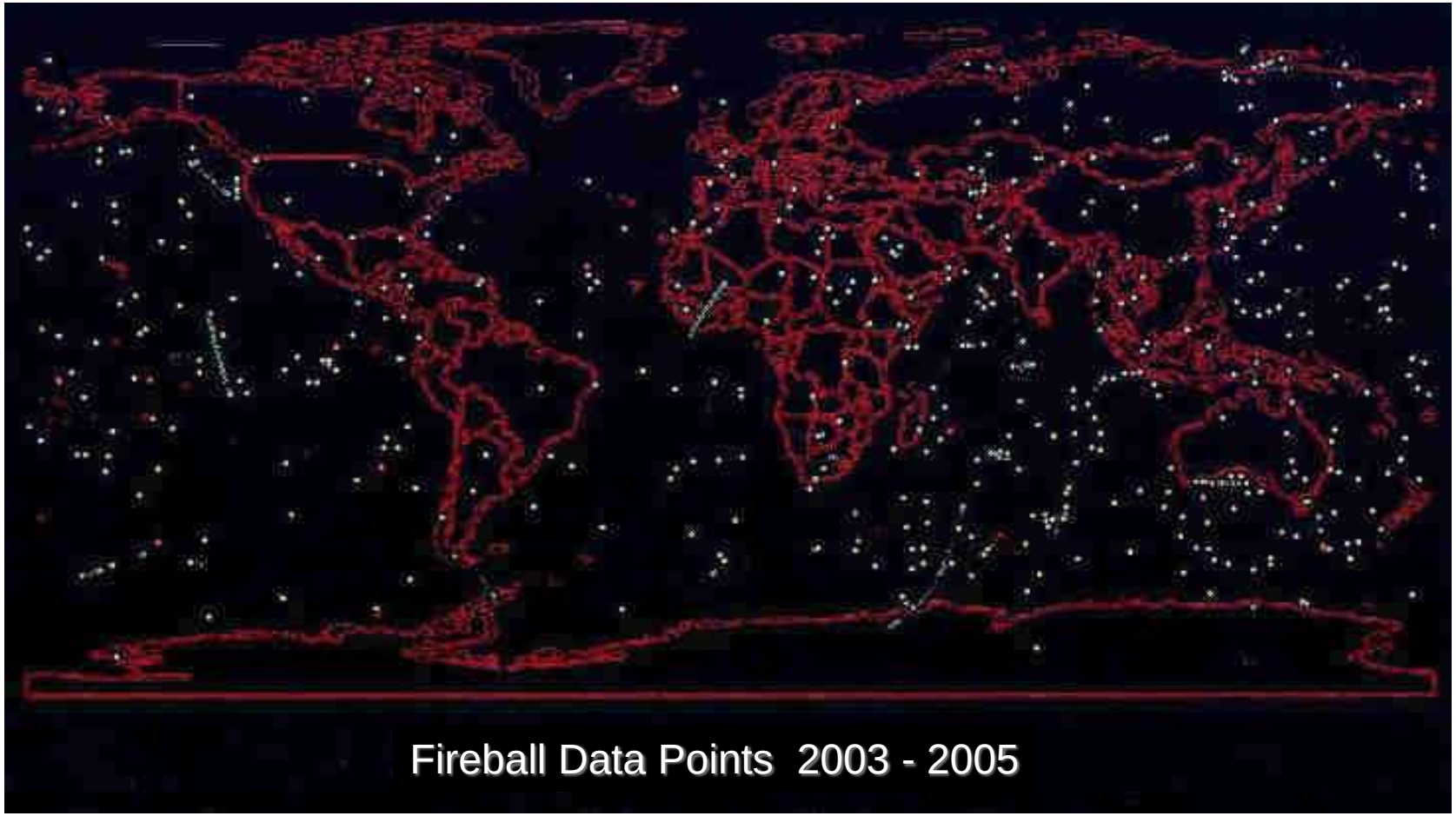
Diameter – 1.2 km
Age – 50,000 yrs

Impactor size - ~50m
Energy released = ~10Mt

Confirmed Craters North America

Courtesy University of New Brunswick, Canada

"The Hard Rain"



"U.S. early warning satellites detected a flash that indicated **an energy release comparable to the Hiroshima burst. We see about 30 such bursts per year,** but this one was one of the largest we have ever seen. The event was caused by the impact of a small asteroid, probably about 5-10 meters in diameter, on the earth's atmosphere."

--Statement of **Brigadier General Simon P. Worden**, Deputy Director for Operations, United States Strategic Command before the House Science Committee Space and Aeronautics Subcommittee on Near-Earth Object Threat October 3, 2002

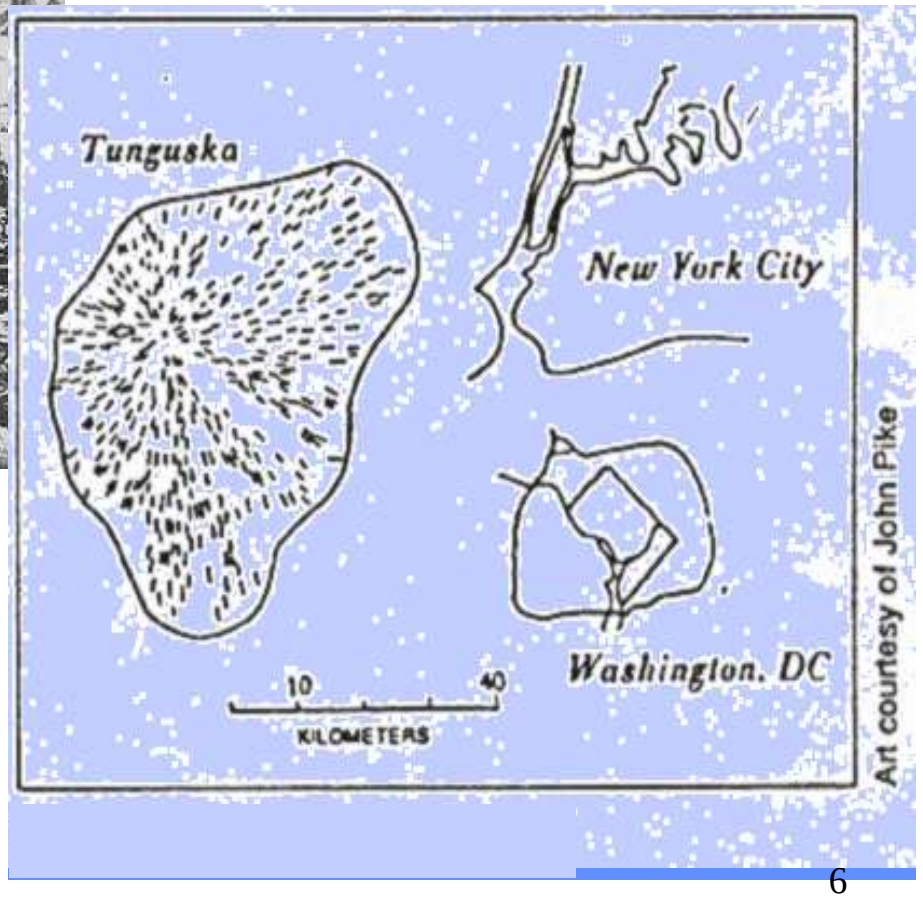
A Low Probability but High Consequence Risk

Estimated Impact Frequencies and Energies

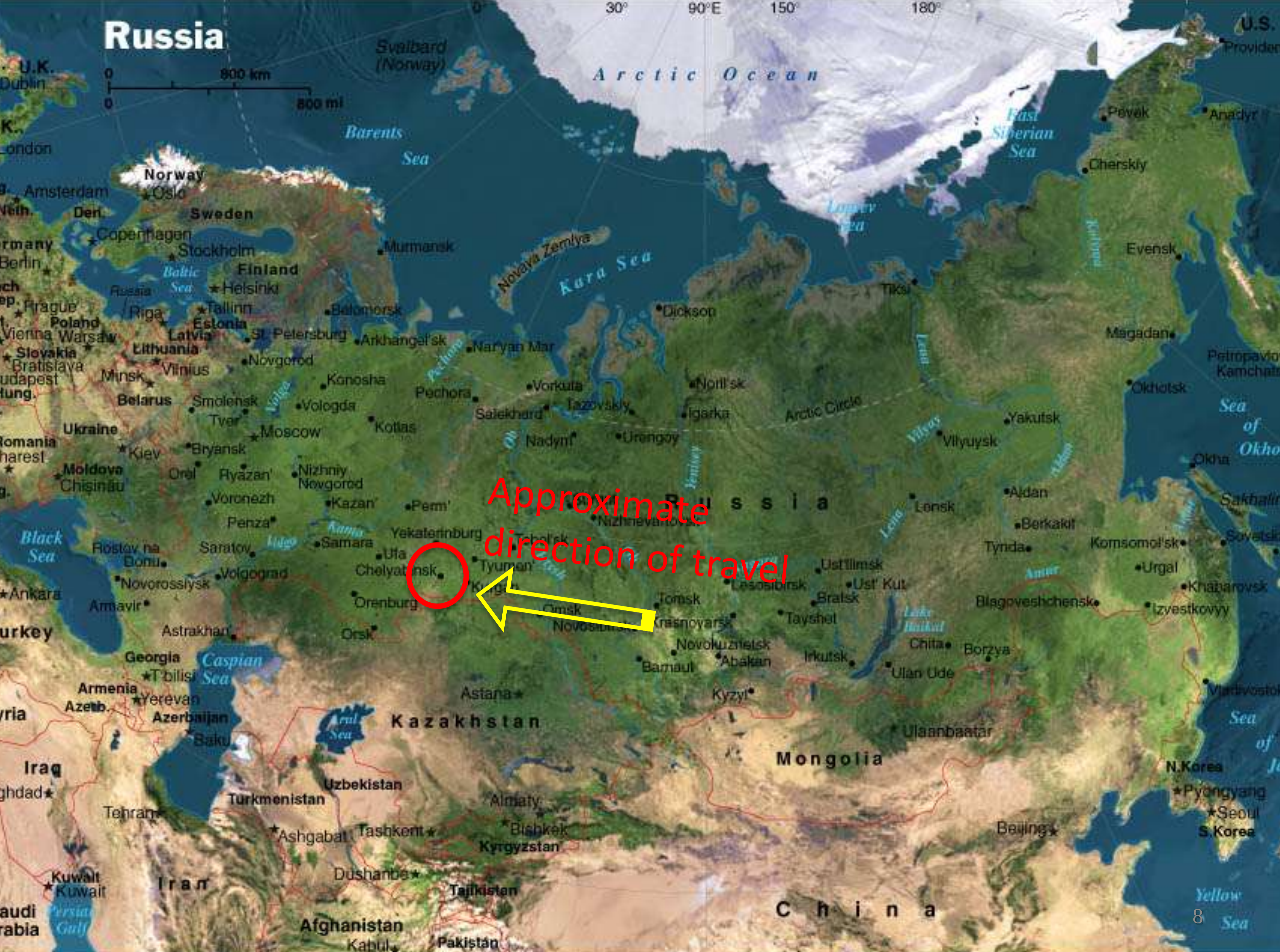
Type of Event	Diameter of Impact Object	Impact Energy(MT)	Average Impact Interval (years)
High altitude break-up	**< 30 m**	**<5**	**1 - 50**
Tunguska-like event	**> 30 m**	**>5**	**250 - 500**
Regional event	**> 140 m**	**~150**	**5,000**
Large sub-global event	**> 300 m**	**~2,000**	**25,000**
Low global effect	**> 600 m**	**~30,000**	**70,000**
Medium global effect	**> 1 km**	**>100K**	**1 million**
High global effect	**> 5 km**	**> 10M**	**6 million**
Extinction-class Event	**> 10 km**	**>100M**	**100 million**

The TUNGUSKA EVENT

June 1908 – 104 years ago



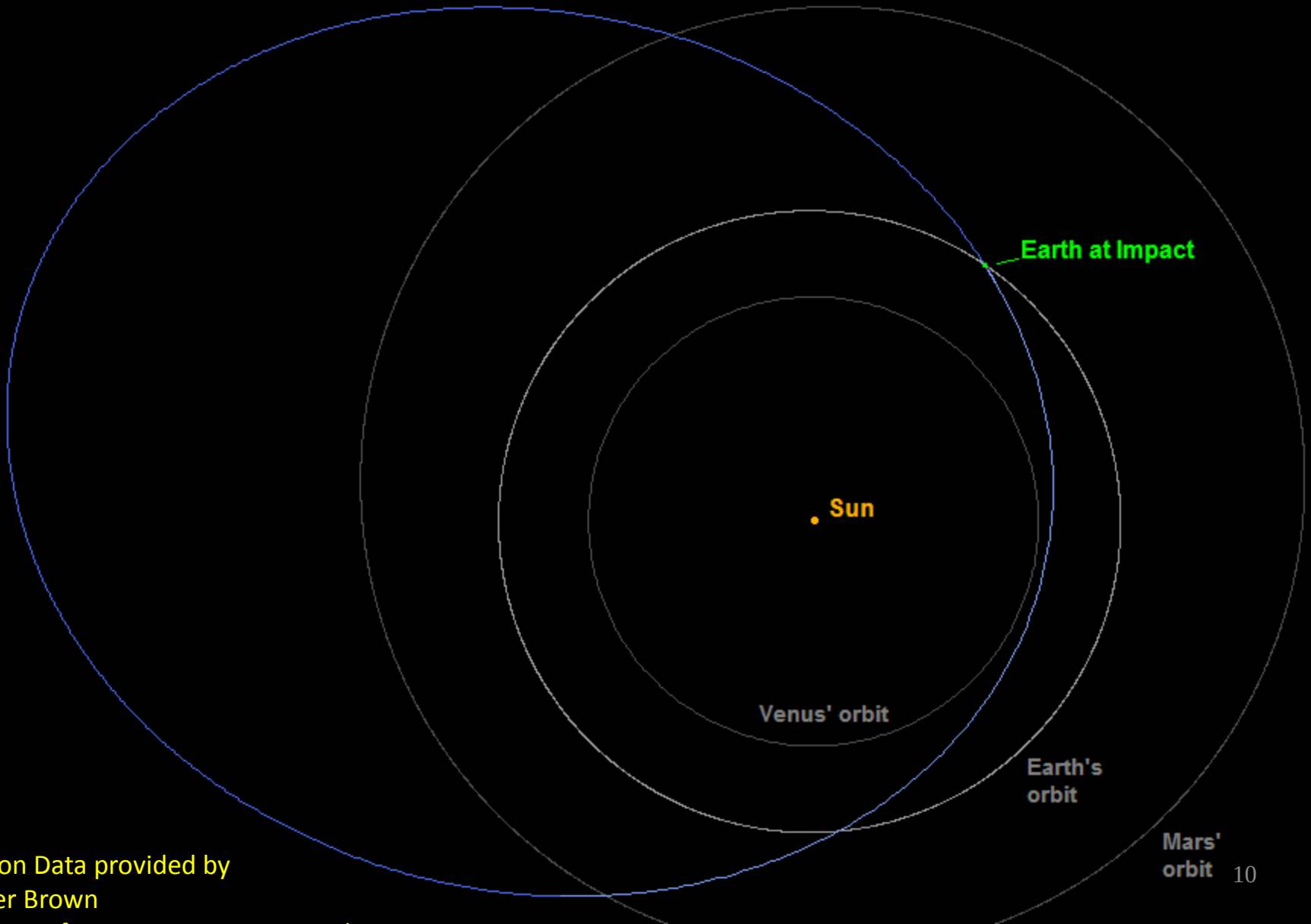
And Now Chelyabinsk


Russia
0 800 km
0 800 mi
Svalbard (Norway)
Arctic Ocean
Barents Sea
Kara Sea
Novaya Zemlya
East Siberian Sea
Laptev Sea
Sea of Okhotsk
Black Sea
Caspian Sea
Aral Sea
Lake Baikal
Baltic Sea
Yellow Sea
Norway
Sweden
Finland
Estonia
Latvia
Lithuania
Belarus
Ukraine
Moldova
Romania
Poland
Slovakia
Turkey
Georgia
Armenia
Azerbaijan
Iraq
Iran
Kuwait
Afghanistan
Pakistan
Turkmenistan
Uzbekistan
Kazakhstan
Kyrgyzstan
Tajikistan
Mongolia
China
N.Korea
S.Korea
Russia
Oslo
Copenhagen
Stockholm
Helsinki
Tallinn
Riga
Vilnius
Minsk
Kiev
Moscow
St. Petersburg
Murmansk
Arkhangel'sk
Novgorod
Vologda
Kotlas
Smolensk
Tver'
Bryansk
Orel
Ryazan'
Nizhniy Novgorod
Voronezh
Kazan'
Perm'
Penza
Saratov
Samara
Ufa
Volgograd
Rostov na Donu
Novorossiysk
Armavir
Astrakhan'
Yekaterinburg
Chelyabinsk
Orenburg
Orsk
Tyumen'
Omsk
Tomsk
Krasnoyarsk
Novokuznetsk
Barnaul
Abakan
Kyzyl
Irkutsk
Bratsk
Ust' Kut
Ust'Ilimsk
Tayshet
Lesosibirsk
Chita
Borzya
Ulan Ude
Blagoveshchensk
Khabarovsk
Komsomol'sk
Urgal
Tynda
Berkakit
Aldan
Lensk
Yakutsk
Vilyuysk
Magadan
Okhotsk
Okha
Evensk
Pevek
Anadyr
Cherskiy
Tiksi
Dicksop
Noril'sk
Igarka
Urengoy
Nadym
Salekhard
Vorkuta
Pechora
Naryan Mar
Konosha
Belomorsk
Astana
Almaty
Bishkek
Tashkent
Ashgabat
Dushanbe
Tehran
Baku
Yerevan
T'bilisi
Ulaanbaatar
Beijing
Pyongyang
Seoul
Kabul
Arctic Circle
Approximate direction of travel

What we know now

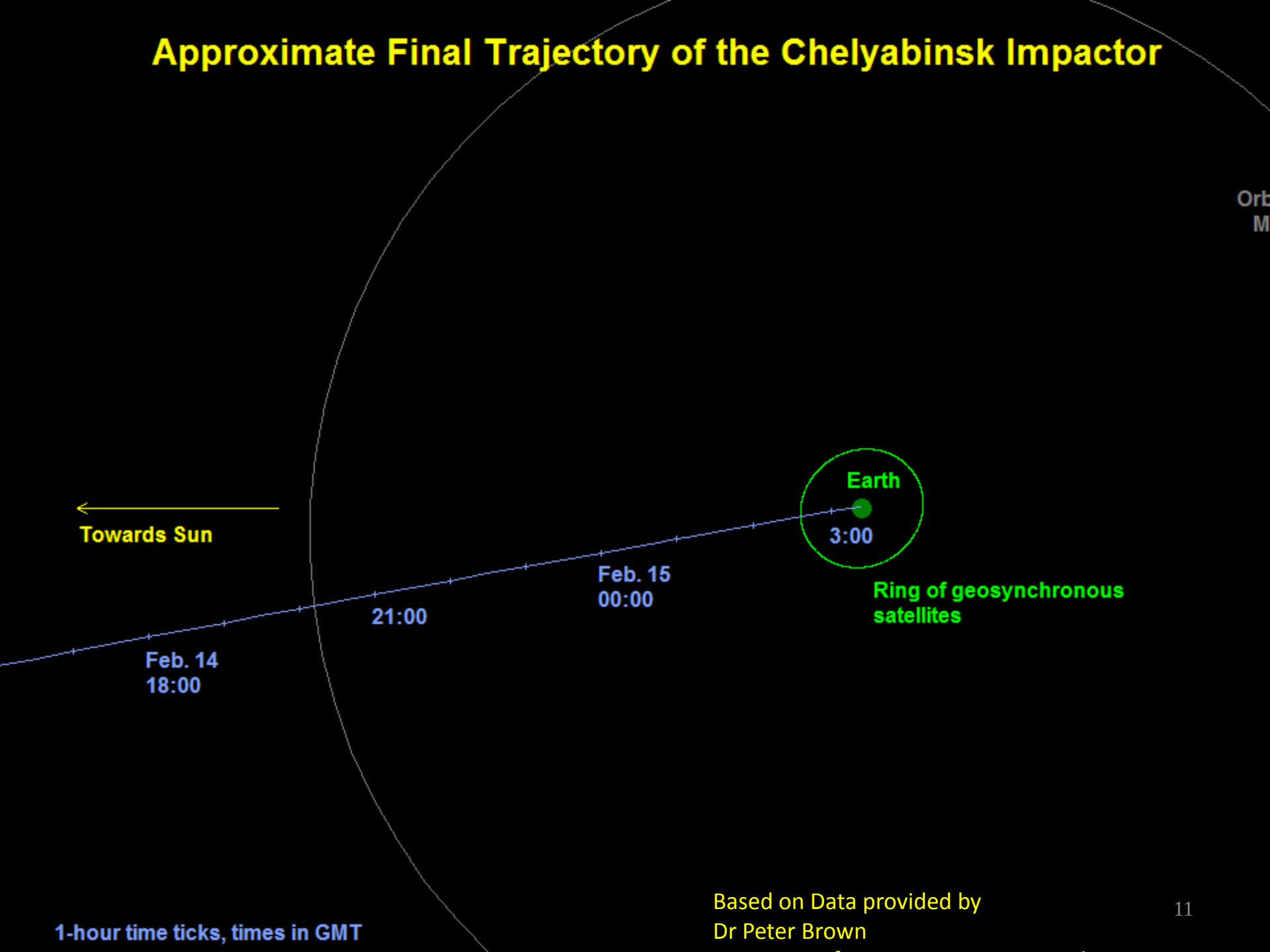
- Impact event occurred at 3:20:26 UTC (9:20 AM local time); Trajectory was ~east to west across Chelyabinsk, Russia (Southern Urals)
  - Observed from Tyumen, Ekaterinaburg, and Northern Kazakhstan
- Size ~17-20 meters
  - ~ 9,000 to 11,000 metric tons
  - Energy of this impact released 440 - 470 of kilotons equivalent TNT
  - Altitude of explosion at ~23 km
  - Velocity of impact 18 km/s (> 40,200 mph)
  - Not related to 2012 DA_{14} flyby [15 Feb 2013; that flyby was South to North]
- Largest reported fireball since Tunguska impact (on 30 Jun 1908)
- Much larger than 2008 TC_3 (which impacted in the Sudan) and ~1/10 the size of 2012 DA_{14}
- Reports that a few fragments have been recovered ~80 km west of Chelyabinsk (near a village called Satka)
- Blast wave damaged 4000+ structures (shallow graze ~15° entry; airburst and subsequent shockwaves from explosion)
- Report of 1200+ injured (no deaths), largely due to broken glass

Estimated Orbit About the Sun of the Chelyabinsk Impactor



Based on Data provided by
Dr Peter Brown

Approximate Final Trajectory of the Chelyabinsk Impactor



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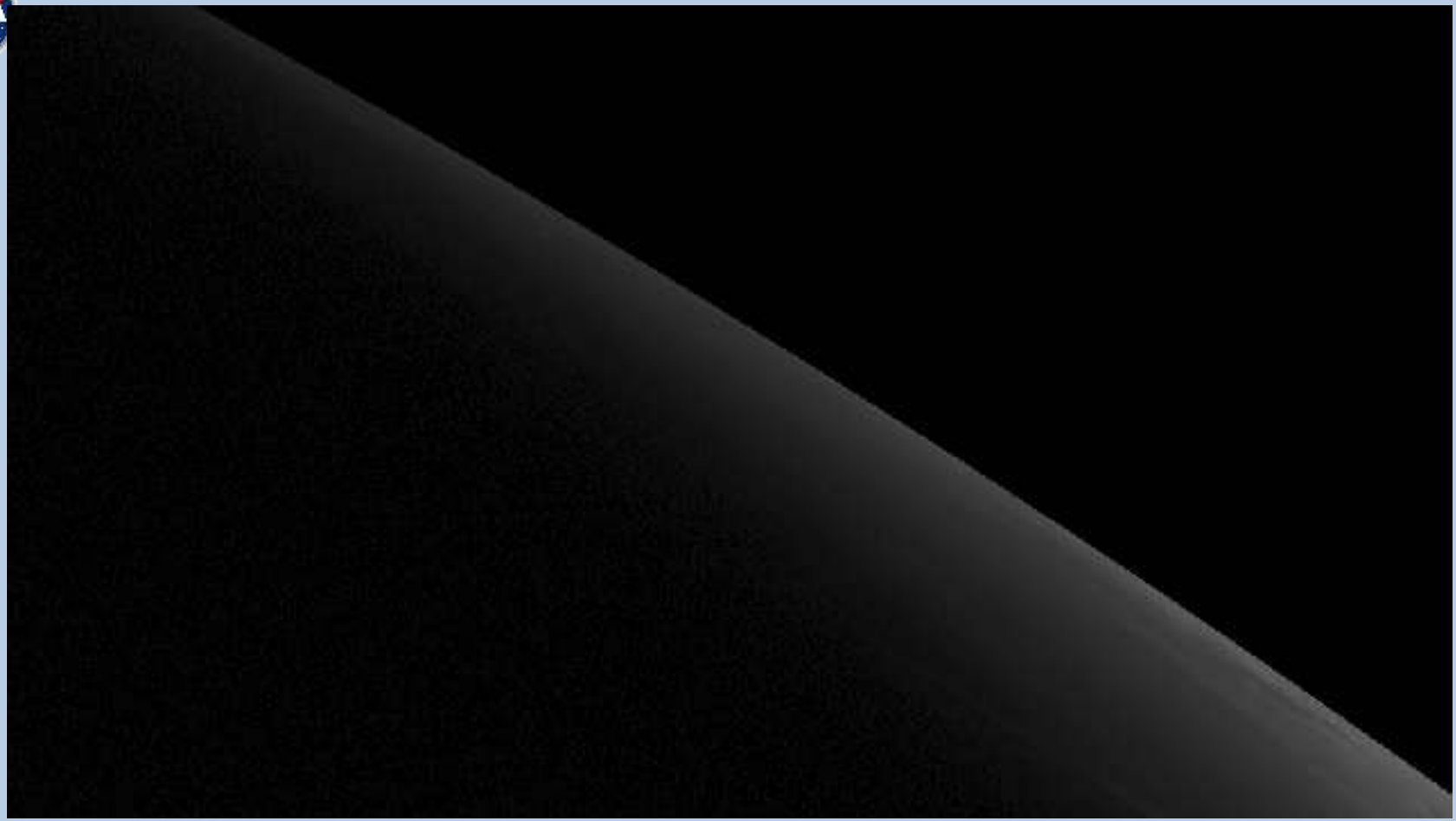


This animated GIF image shows the meteor that entered the atmosphere above Chelyabinsk, Russia the morning of February 15, 2013 around 9:20 am local time, 0320Z. The GIF consists of 8 separate images starting at 0300Z and proceeding in 15 minute increments until 0445Z, at which time the vapor trail blends into the reflected light of the morning sun. The images show the horizon taken at the farthest extent of the EUMETSAT METEOSAT-10 satellite's high resolution visible channel, near latitude 55 north, longitude 61 west. Courtesy European Organisation for the Exploitation of Meteorological Satellites, and NOAA

Terminology

- "Near Earth Objects (NEOs)"- any small body (comet or asteroid) passing within 1.3 Astronomical Unit (AU) of the Sun
  - 1 AU is the distance from Earth to Sun = ~ 150 million kilometers (km)
  - NEOs are predicted to pass within ~ 45 million km of Earth's orbit
  - Population of:
    - Near Earth Asteroids (NEAs)
    - Near Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      - 91 currently known
- "Potentially Hazardous Objects (PHOs)" – small body that has potential risk of impacting the Earth at some point in the future
  - NEOs passing within 0.05 AU of Earth's orbit
    - ~ 8 million km = 20 times the distance to the Moon
  - Appears to be about 20% of all NEOs discovered
- NEOs accessible by human mission are a subset of PHOs

NEO Observation Program

US component to International Spaceguard Survey effort

Has provided 99% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May, 1998 to find at least 90% of 1 km NEOs

- Averaged ~$4M/year Research funding 2002-2010
- Starting with FY2012, now has $20.5 M/year

Program Objective: Discover ≥ 90% of NEOs larger than 140 meters in size as soon as possible

NASA Authorization Act of 2005 provided additional direction)

"...plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020].

NASA's NEO Search Program

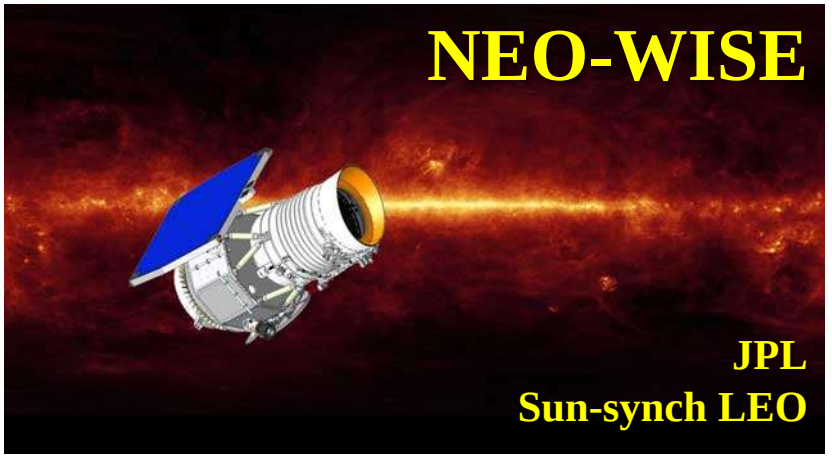
(Current Systems)

Minor Planet Center (MPC)
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

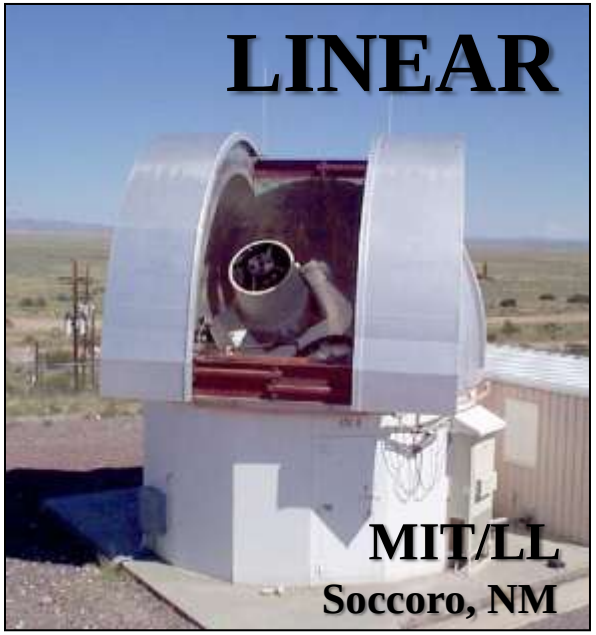
www.cfa.harvard.edu/iau/mpc.html

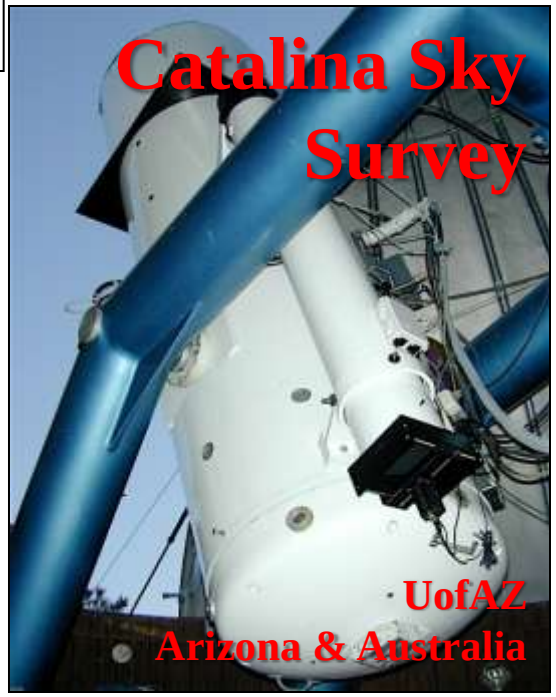
NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

http://neo.jpl.nasa.gov/

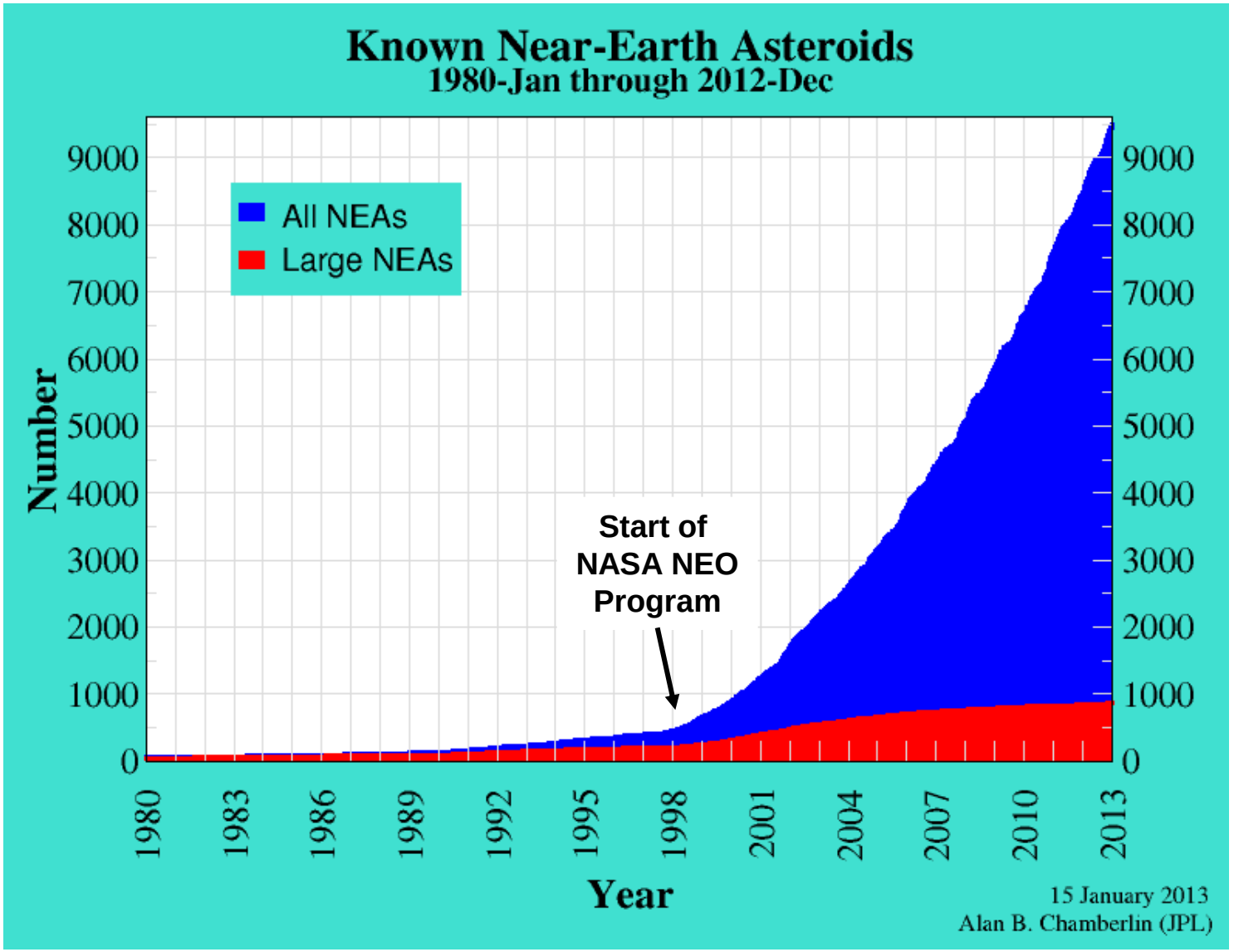


End of Operations Feb 2011, Analysis Of Data Continues





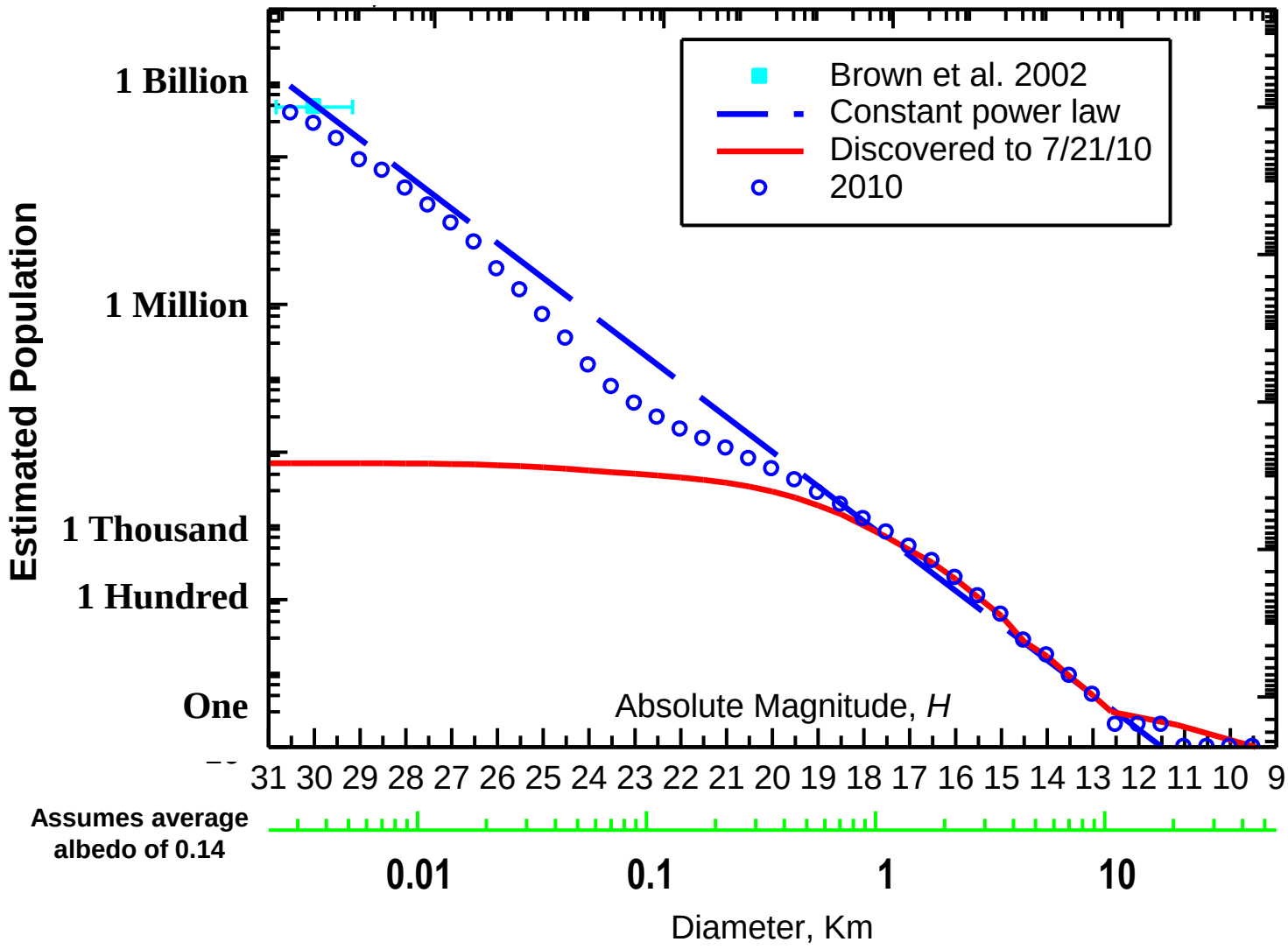
Known Near Earth Asteriod Population



9726
3/24/13

861
3/24/13

Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)



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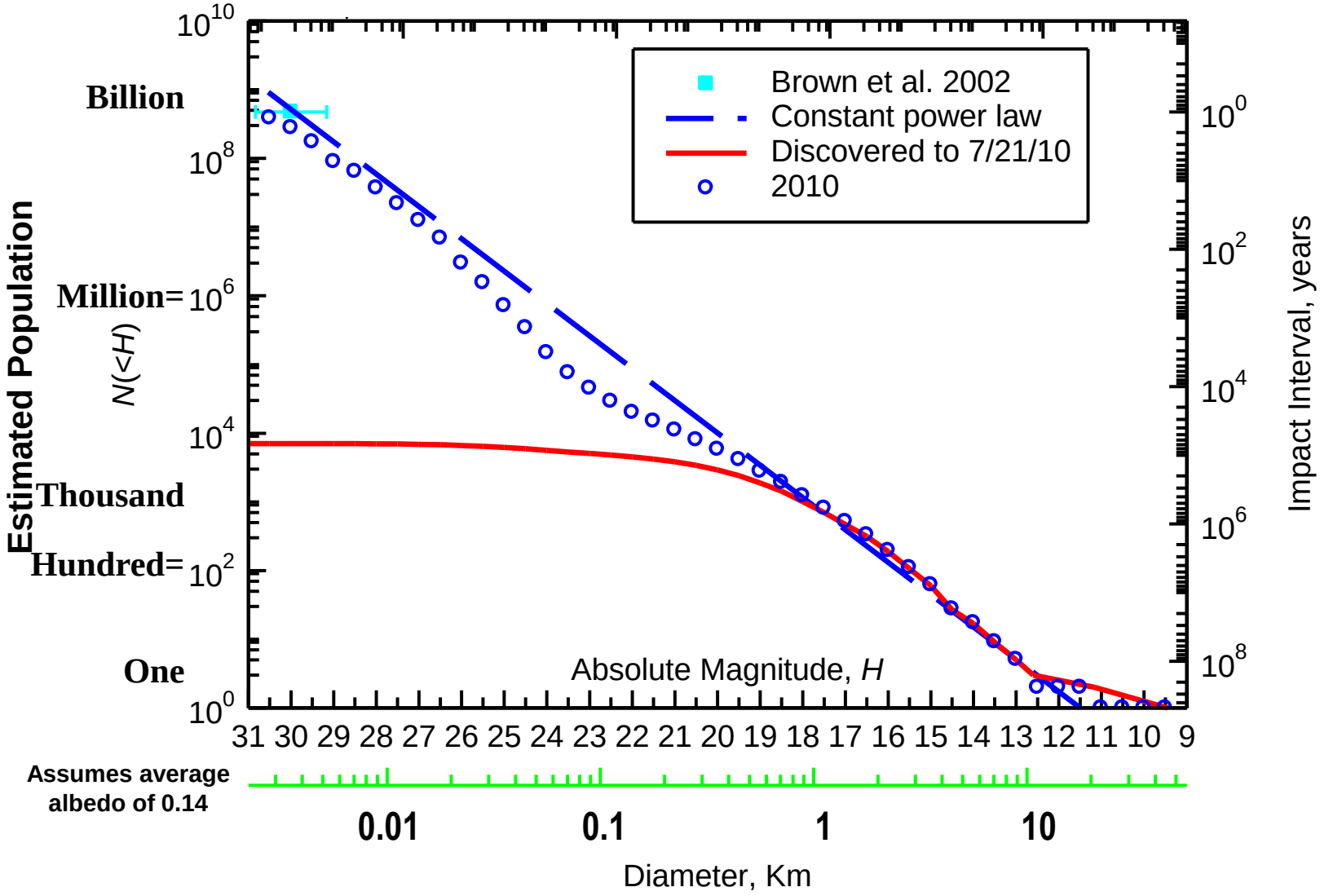

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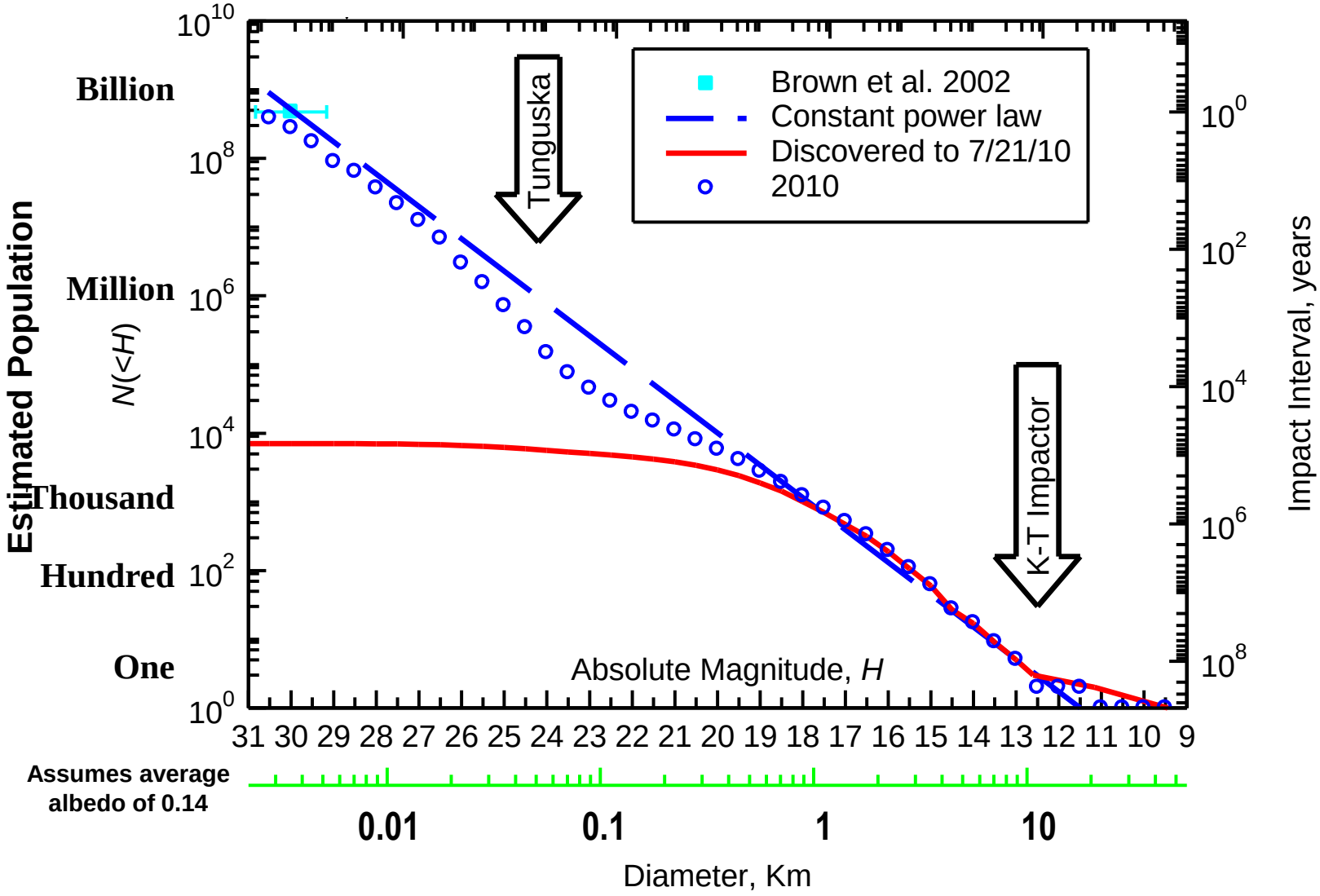
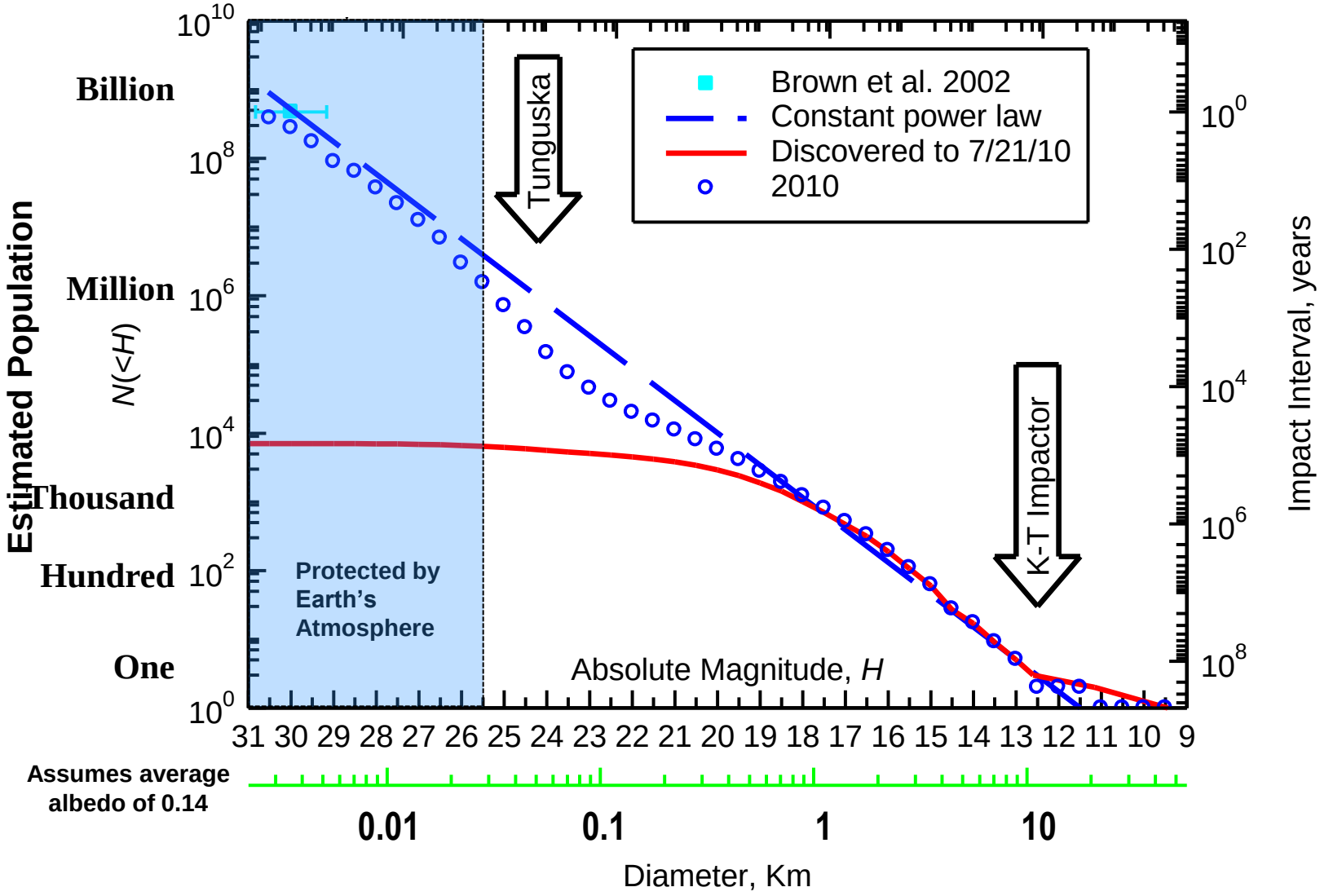


Chicxulub Crater – KT Impactor

Demise of the Dinosaurs

Layer of Iridium across Earth's surface

Population of NEAs by Size, Brightness, Impact Energy & Frequency (Harris 2010)



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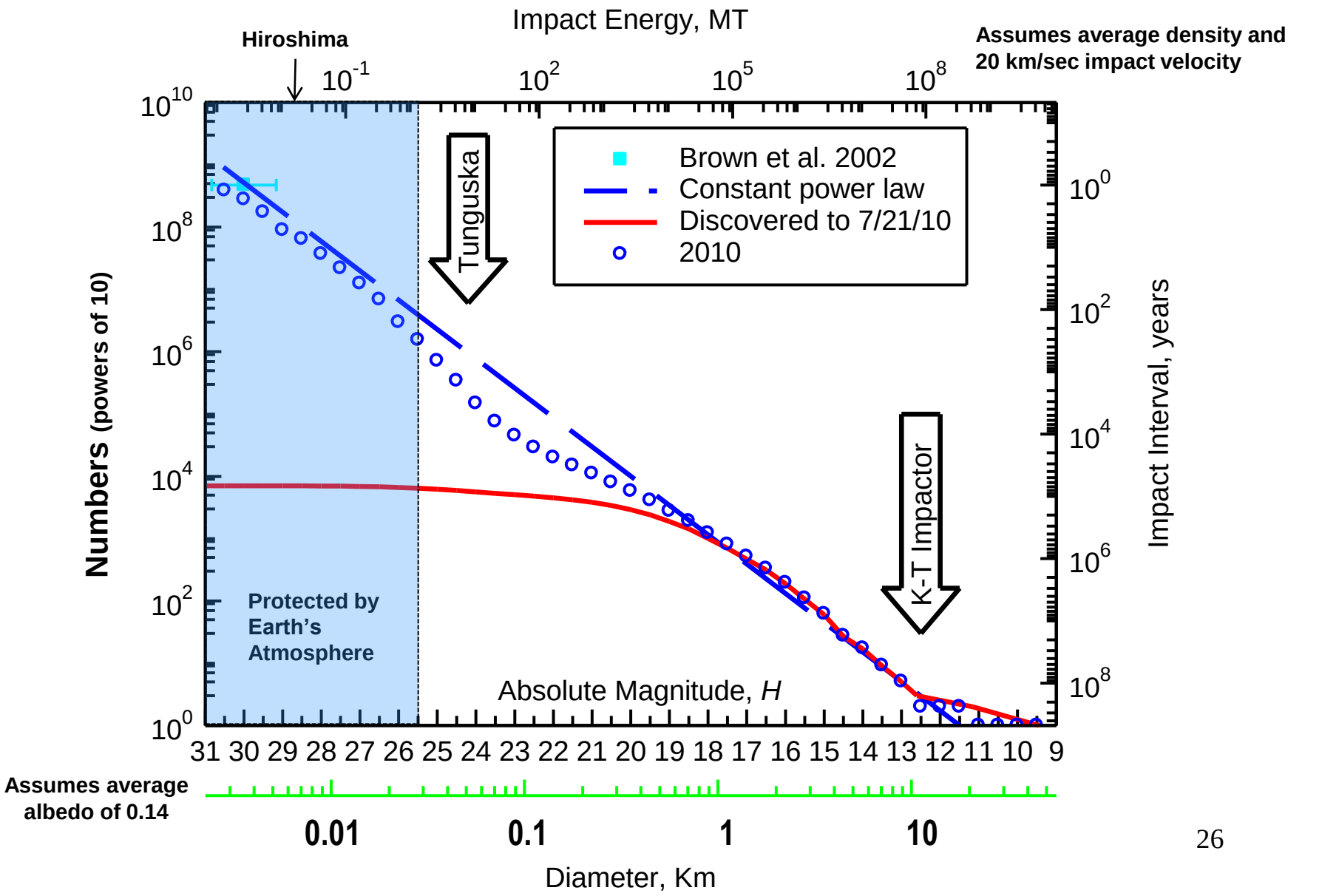

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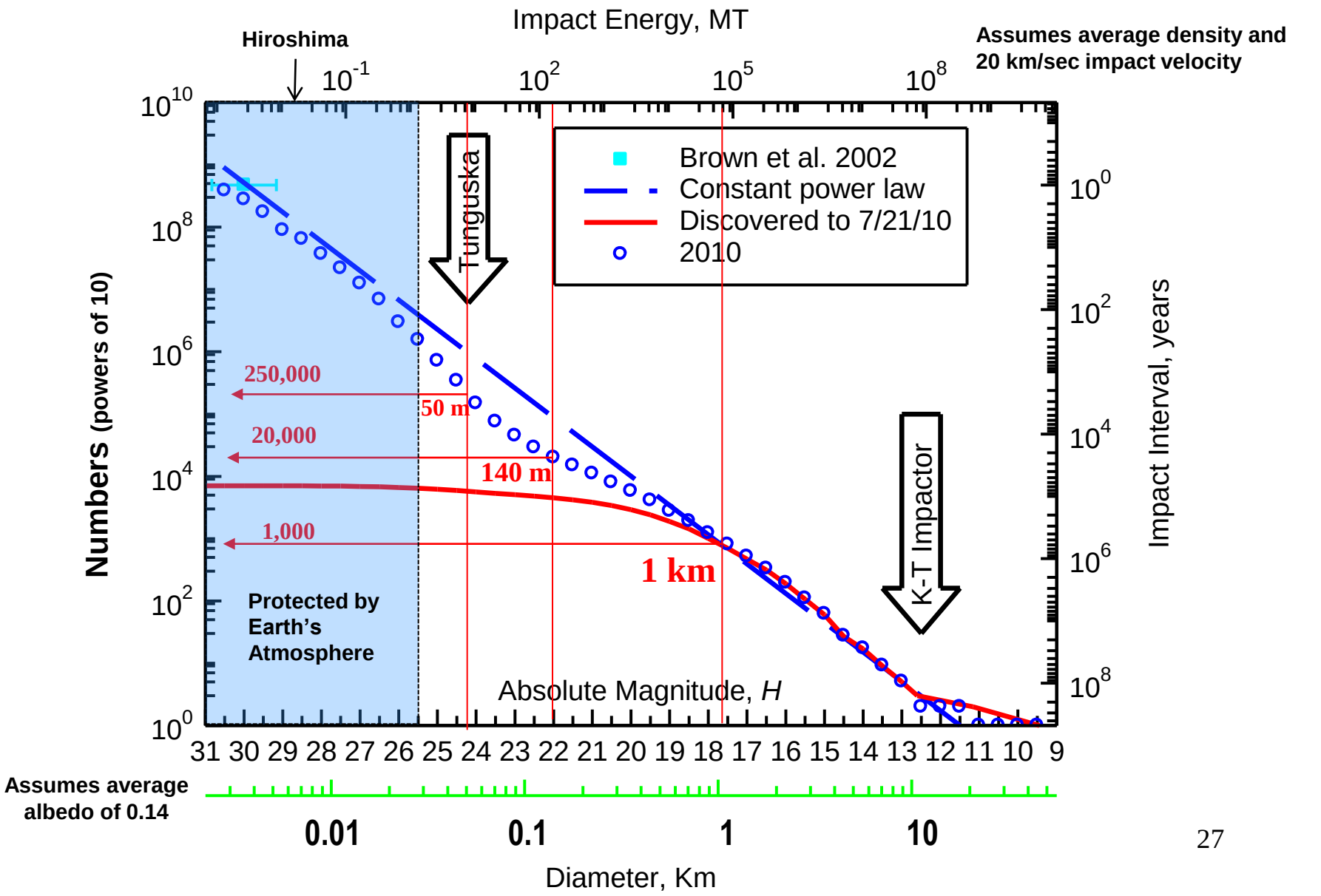
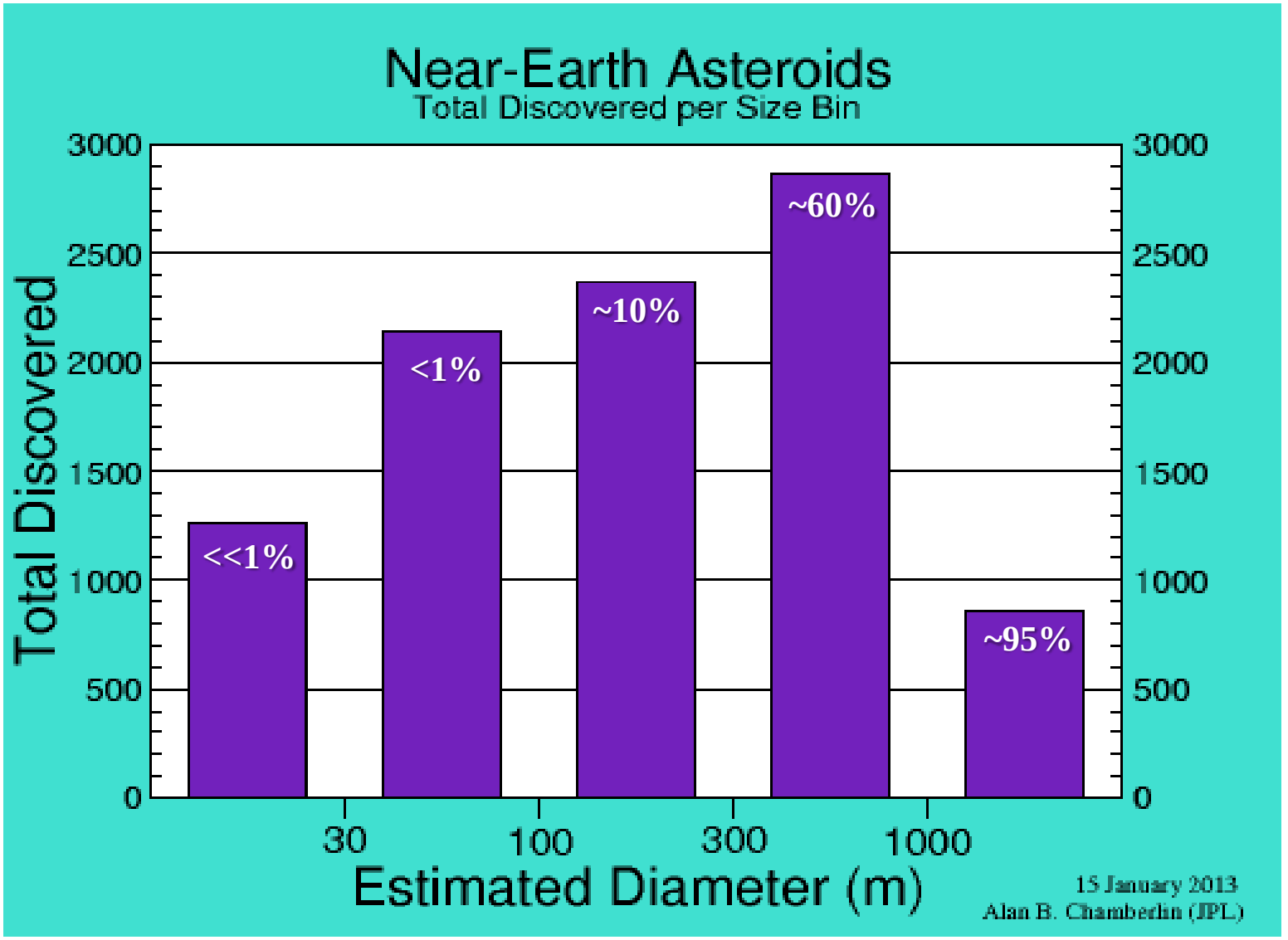
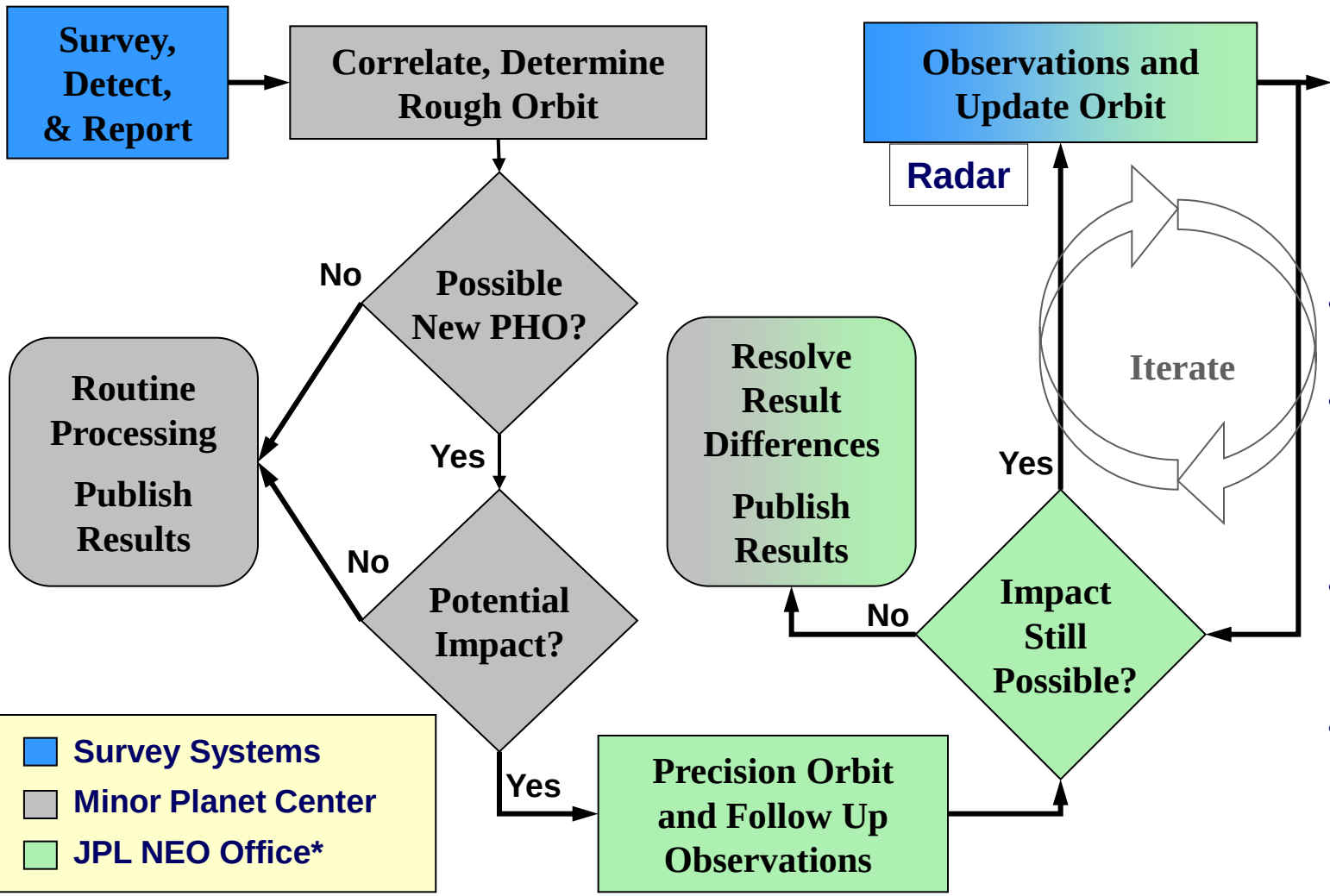


Known Near Earth Asteroid Population



Spaceguard Survey Catalog Program

Current Spaceguard Survey Infrastructure and Process



Alerts to NASA HQ

- **MPC** - PHO of interest
- **MPC** - possible close approach
- **JPL** - reports potential for impact
- **JPL** - publishes probability of impact

* In parallel with NEODyS

Increased Radar Studies

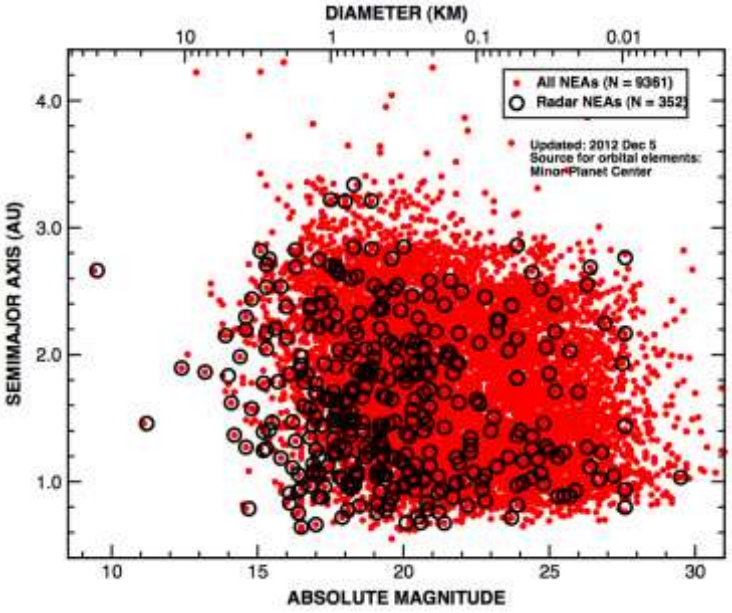
Observations on the limited number of accessible objects, but next best thing to a flyby

– Detections/year from Goldstone and Arecibo doubled

– Required for timely precision orbit determination

– Characterization with sufficient signal strength

- Shape, spin-state, surface structure
- Satellites (an then derived mass)



Shape, Size of 4179 Toutatis

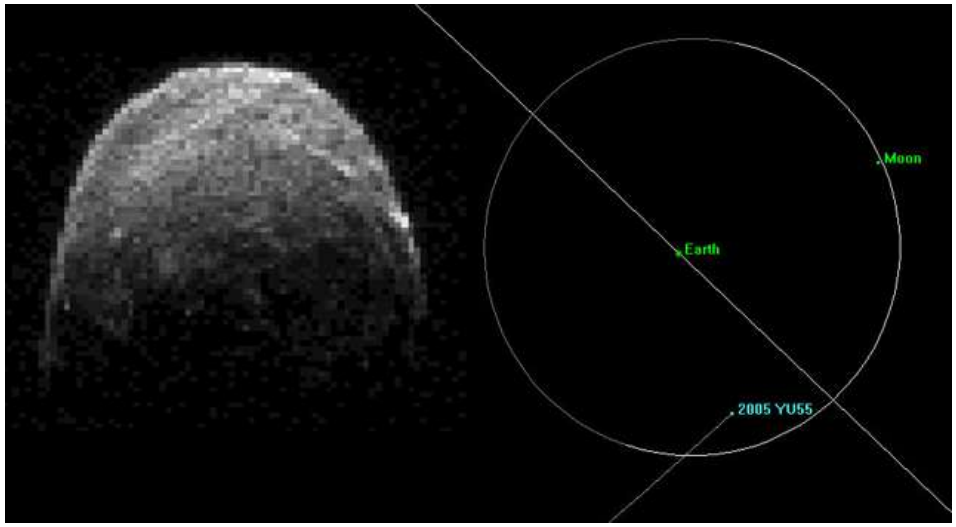
Study of Shape, Size, Motion and Mass of 66391 (1999 KW4)

Close Approaching Asteroids in 2011

Object	Closest Approach Date -Time	Min Dist. x Lunar	Relative Velocity (km/sec)	H Mag(v)	Size meters (est)
2011 CQ1	2011-Feb-04 19:38	0.03	9.69	32.0	1
2011 MD	2011-Jun-27 17:00	**0.05**	6.70	28.1	14
2011 CF22	2011-Feb-06 11:39	0.1	19.60	30.9	3
2011 GP28	2011-Apr-06 19:39	0.2	14.80	29.4	6
2011 TO	2011-Sep-28 15:25	0.3	8.87	26.3	32
2011 BW11	2011-Jan-25 06:33	0.3	23.95	28.3	12
2011 EY11	2011-Mar-07 03:26	0.3	11.86	28.6	10
2011 YC40	2011-Dec-28 02:29	0.3	11.36	29.7	5
2011 AM37	2011-Jan-11 11:46	0.3	4.41	29.7	5
2011 CA7	2011-Feb-09 19:27	0.3	9.33	30.3	4
2011 OD18	2011-Jul-28 08:38	0.4	9.54	26.5	30
2011 UX255	2011-Oct-28 17:42	0.4	26.96	27.4	21
2011 GW9	2011-Apr-06 04:53	0.5	11.36	28.1	14
2011 UT	2011-Oct-12 19:14	0.6	10.17	25.8	40
2011 CA4	2011-Jan-31 04:08	0.6	6.00	27.0	24
2011 SE58	2011-Sep-27 02:46	0.6	15.85	27.6	19

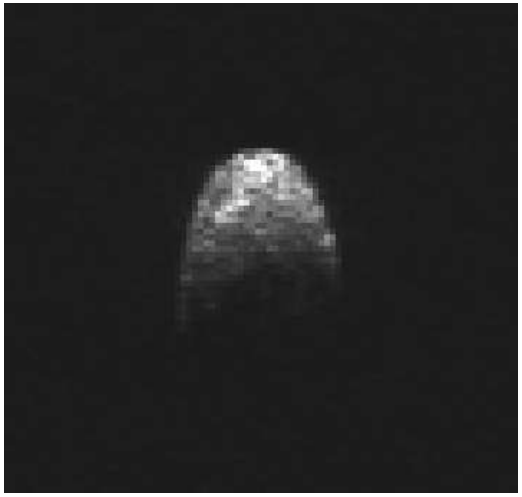
Object	Closest Approach Date -Time	Min Dist. x Lunar	Relative Velocity (km/sec)	H Mag(v)	Size meters (est)
2011 EN11	2011-Mar-03 08:47	0.6	11.21	27.9	16
2011 EM40	2011-Mar-08 04:05	0.6	10.79	28.0	15
2011 YC63	2011-Dec-30 02:16	0.6	18.80	29.0	8
2011 DU9	2011-Feb-23 19:03	0.7	8.92	26.7	28
2011 UL169	2011-Oct-26 02:31	0.7	9.54	28.3	12
2012 AQ	2011-Dec-29 08:32	0.7	3.28	30.7	3
2005 YU55	2011-Nov-08 23:28	0.8	13.72	21.1	**380**
2011 SM173	2011-Sep-30 17:02	0.8	12.71	27.8	17
2011 AN52	2011-Jan-17 23:19	0.8	15.92	28.5	11
2011 XC2	2011-Dec-03 15:20	0.9	20.93	23.0	150
2011 PU1	2011-Jul-24 19:27	0.9	5.60	25.1	60
2011 EB74	2011-Mar-16 21:54	0.9	7.71	26.9	25
2011 BY10	2011-Jan-20 08:29	0.9	7.84	27.3	22
2009 BD	2011-Jun-02 00:51	0.9	1.91	28.3	12
2009 TM8	2011-Oct-17 11:09	0.9	8.18	28.6	10
2011 JV10	2011-May-05 17:13	0.9	5.33	29.7	5
2011 YQ1	2011-Dec-14 14:19	1.0	11.79	25.6	50

Pass of Asteroid 2005 YU55 Observed with Ground-based Radars



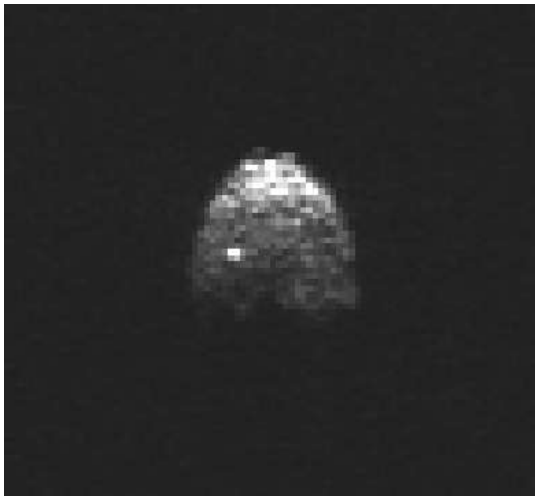
This image of asteroid 2005 YU55 with about 12 foot resolution was obtained by Lance Benner at NASA's Goldstone Radar on Nov. 7, 2011, about one day before closest approach, when the object was at 3.6 lunar distances, which is about 860,000 miles from Earth. NASA/JPL-Caltech

- 2005 YU55 passed by Earth the evening of 8 Nov, 2 at just less than 200,000 miles – within the Moon's orbit
- Earth based planetary radars at Goldstone, CA and Arecibo, PR, were used to track and image the asteroid
- Planetary radar can be used to determine the size and shape of the asteroid, study its surface properties, and help predict any future encounters with the Earth
- The radar imaging shows the asteroid to be roughly spherical, about 1300 feet across, and rotating with a period of about 18 hours
- This event demonstrates how Near Earth Asteroids could be characterized by planetary radar for studies of potential human spaceflight destinations



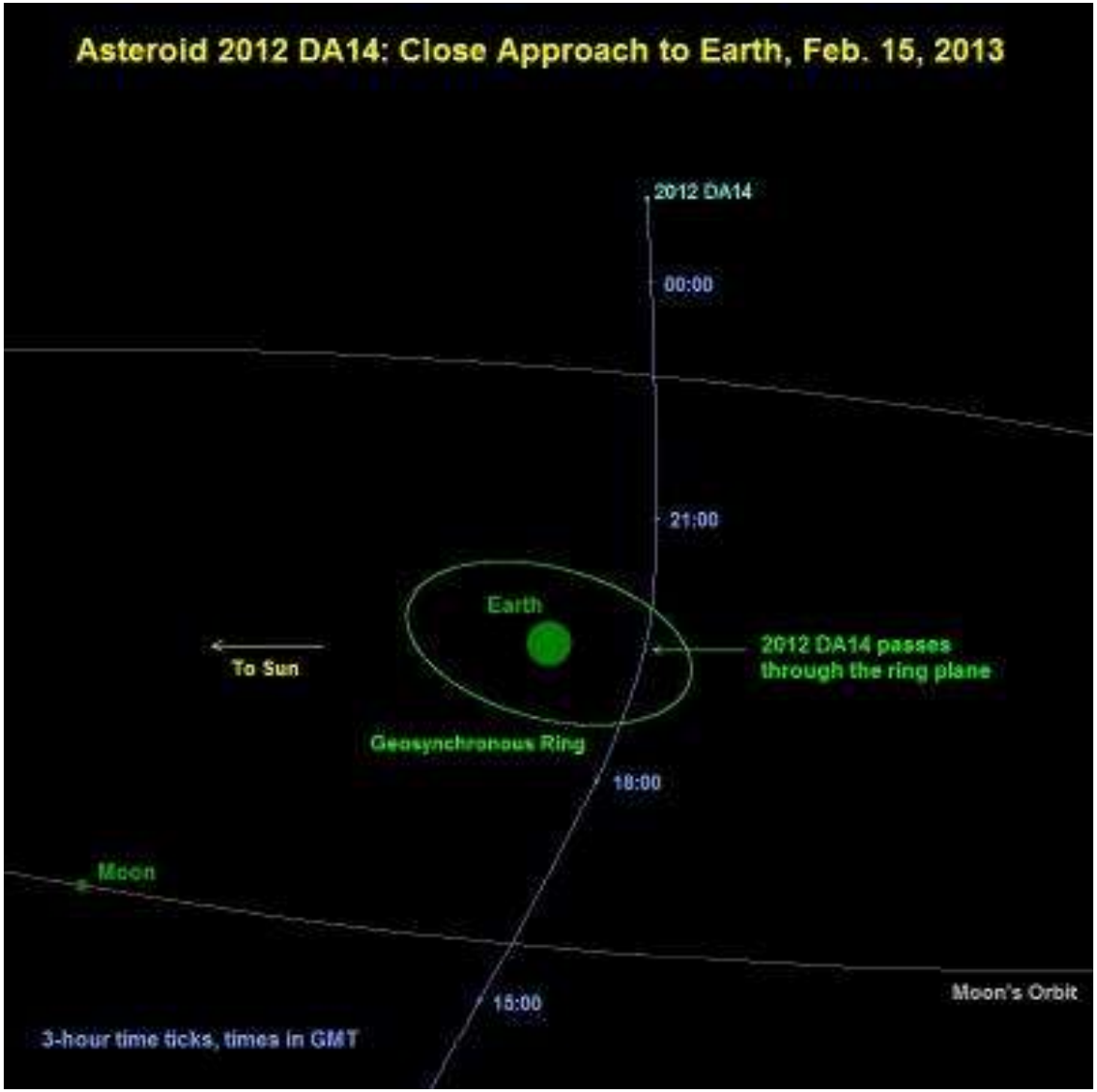
These two radar images were obtained by Patrick Taylor at the Arecibo Planetary Radar on Nov 12. The asteroid was about 2,000,000 miles away and the images show objects of about 25 feet in size. The image on right shows a radar bright feature, possibly a boulder on the asteroid's surface.

The Arecibo Observatory is operated by SRI International under a cooperative agreement with the National Science Foundation, in alliance with Ana G. Méndez-Universidad Metropolitana, and the Universities Space Research Association. The radar operations are funded by NASA.



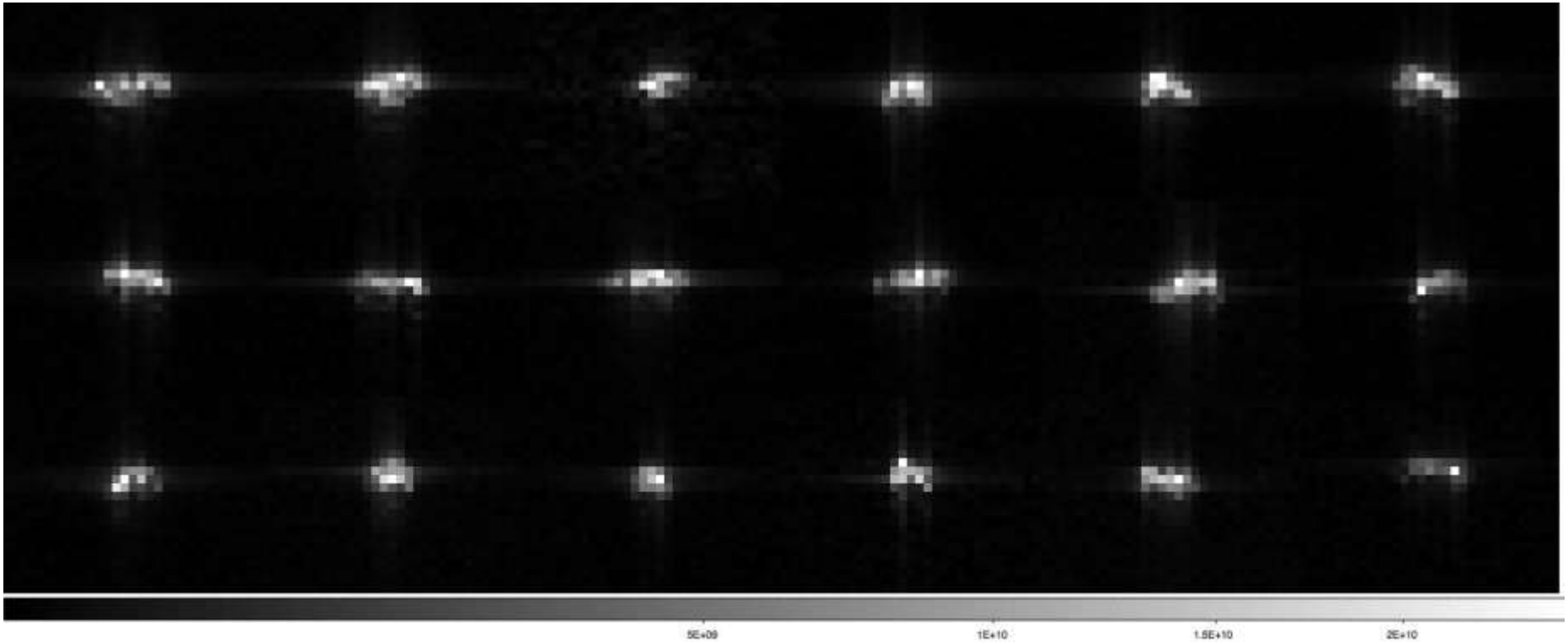
2012 DA14 to Approach Earth Feb 15, 2013

Asteroid 2012 DA14 passed within about 3.5 Earth radii of the Earth's surface on February 15, 2013. Although its size is not well determined, this near-Earth asteroid is thought to be about 45 meters in diameter. Asteroid 2012 DA14 passed inside the Earth's geosynchronous orbit ring, located about 35,800 kilometers above the equator



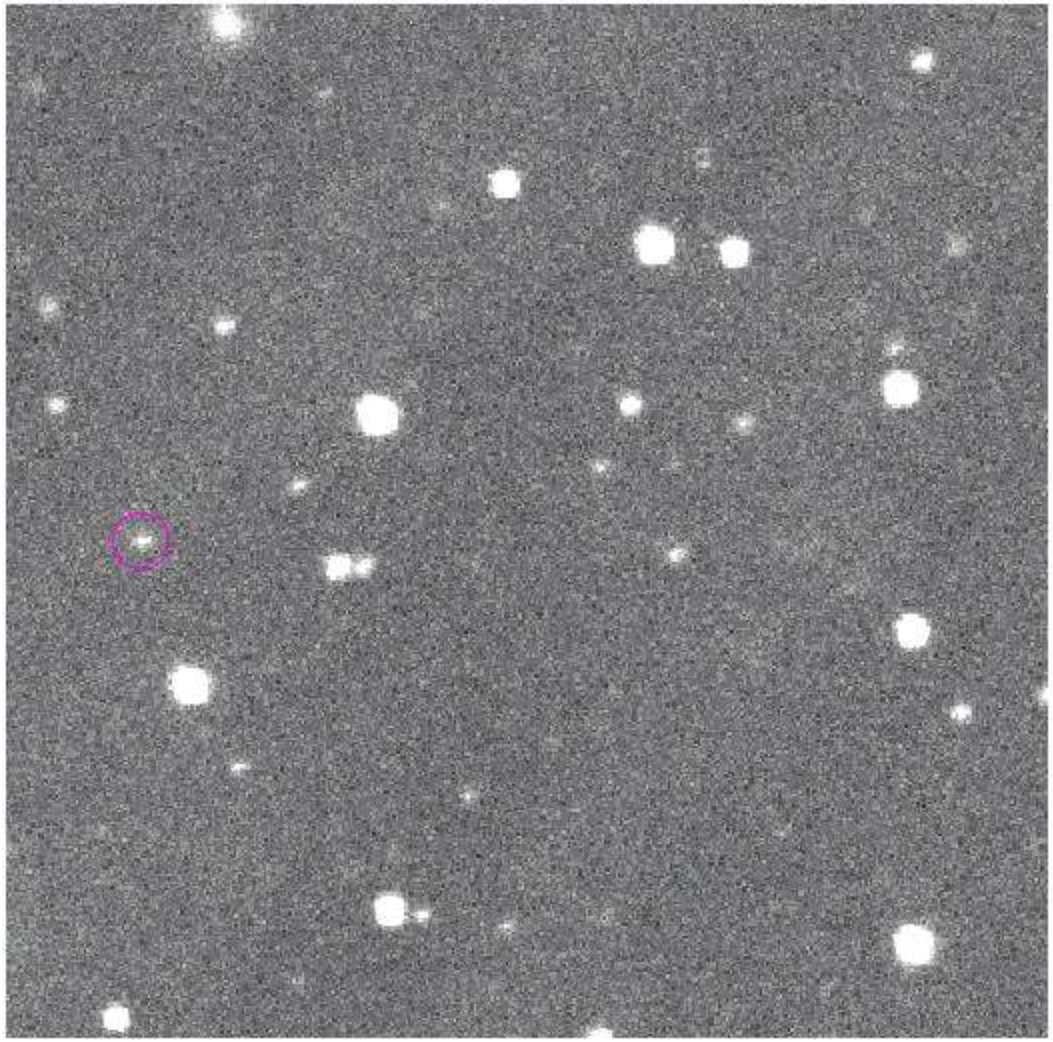
GSSR RADAR Imaging Results

Images of 2012 DA14 spanning nearly 8 hours on Feb. 16. An elongated object is clearly revealed. Based on the changes the aspect ratio for this object is close to 2:1. Preliminary estimates the pole-on dimensions are roughly 40 x 20 meters.



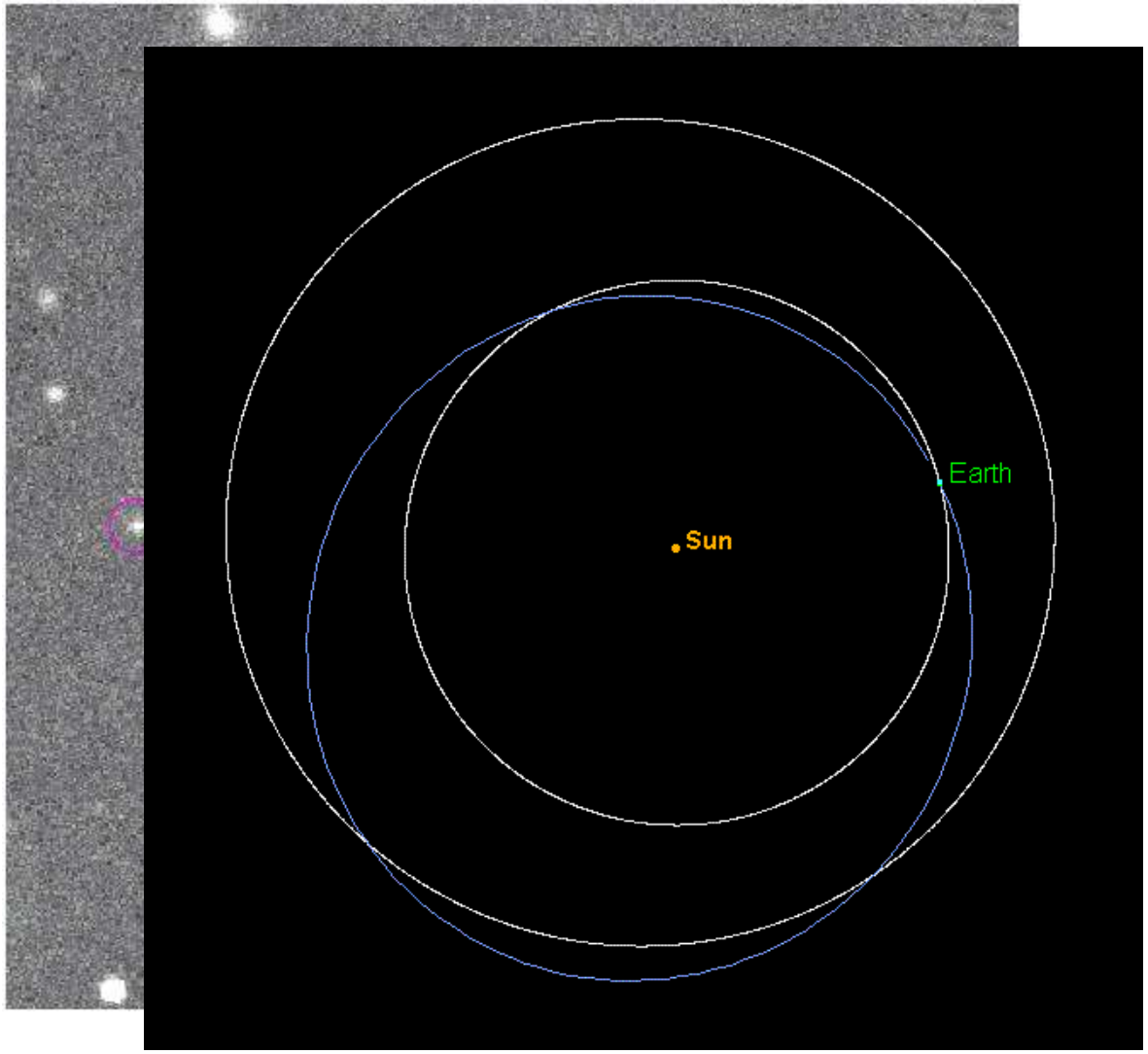
A collage of the 2012 DA14 rotation obtained with a bistatic setup at Goldstone with DSS-14 transmitting and DSS-13 receiving: Feb 16, 00:46 – 08:31 UTC. The round-trip-time (RTT) to 2012 DSS14 changed from ~0.85 s to ~2 s during observations. Each frame is 320 sec of data integration. One full rotation is about 7 hours.

The Short Life of 2008 TC3



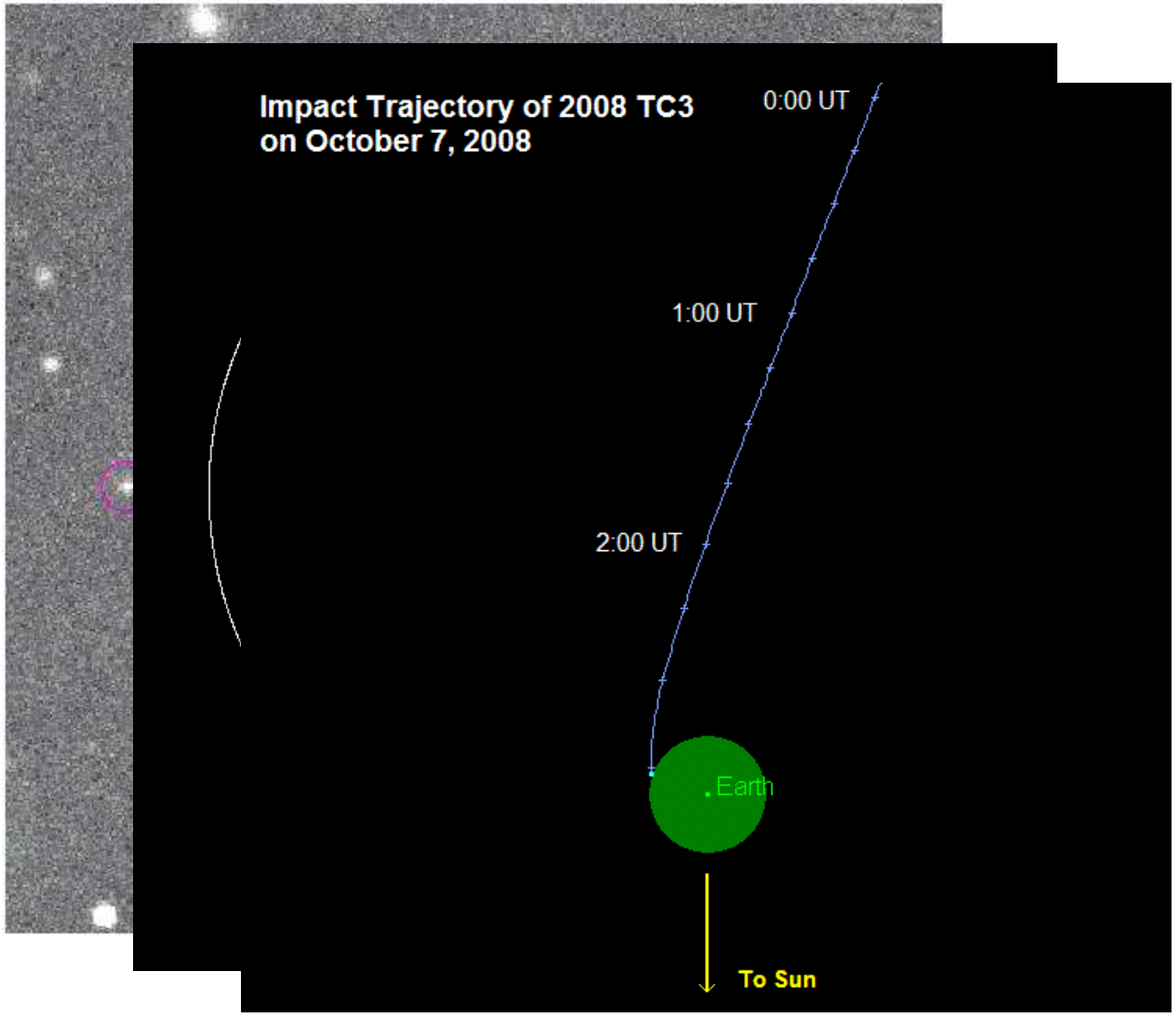
Discovered by
Catalina Sky Survey
Mt Lemmon Survey
Telescope (1.5m) at
0640 on Oct 6, 2008.
~19 Mv

The Short Life of 2008 TC3



Initial MPC orbit determination finds object will impact Earth within 24 hrs. MPC alerts JPL NEO Program Office and HQ NASA

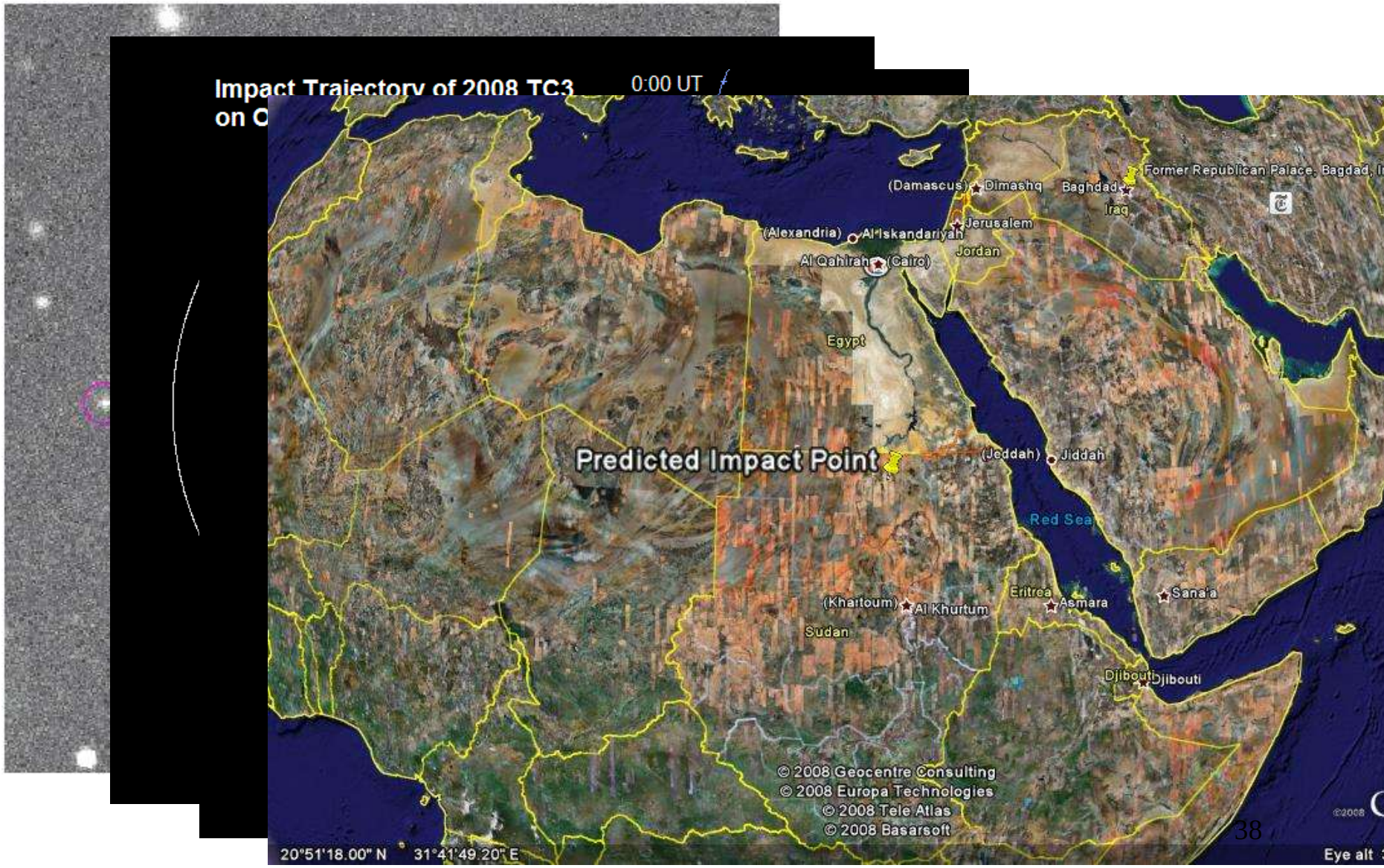
The Short Life of 2008 TC3



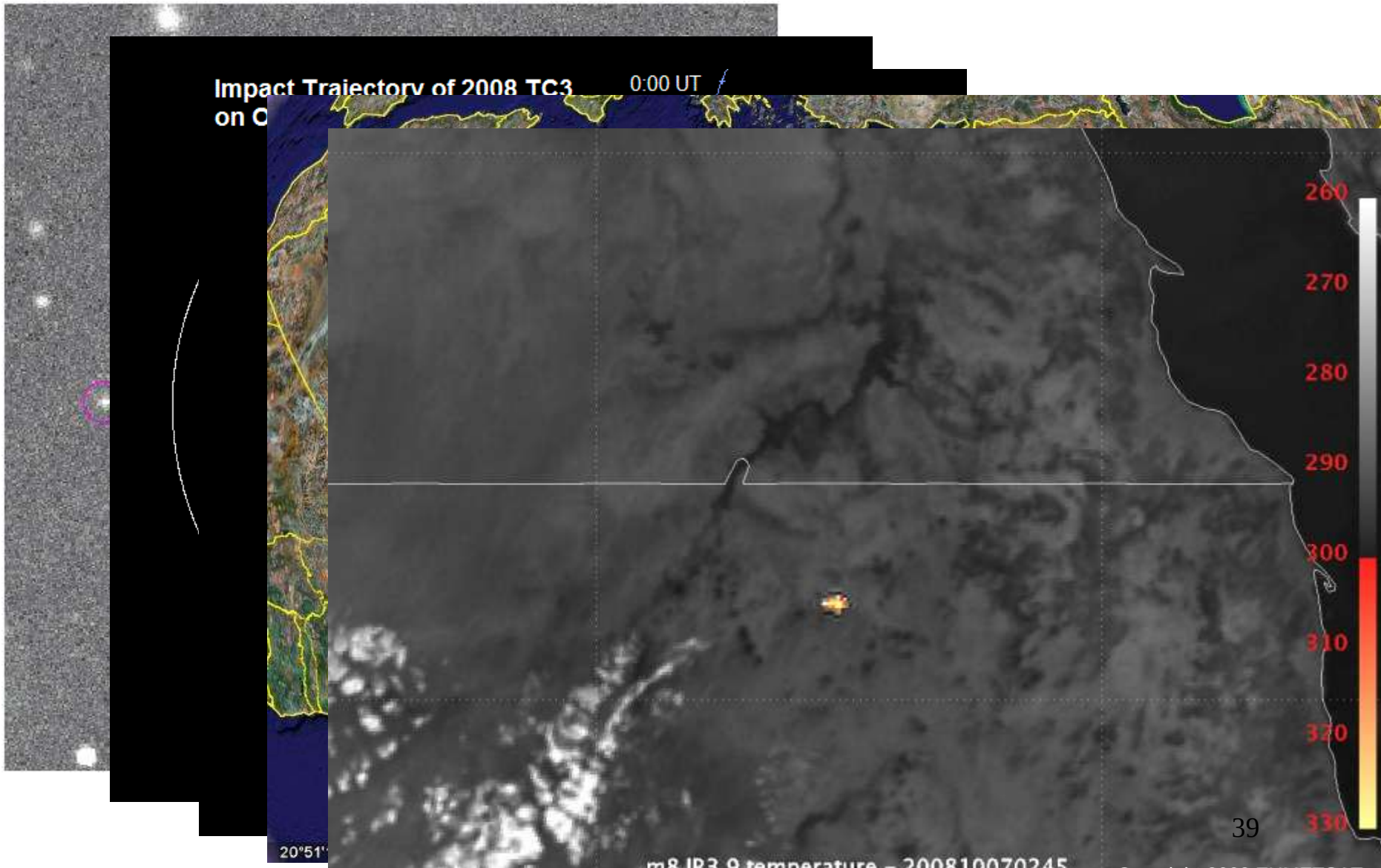
JPL SENTRY run predicts impact at 0245 on 7 Oct, 2008 over northern Sudan

Community responds with 570 observations from 27 observers

The Short Life of 2008 TC3



The Short Life of 2008 TC3



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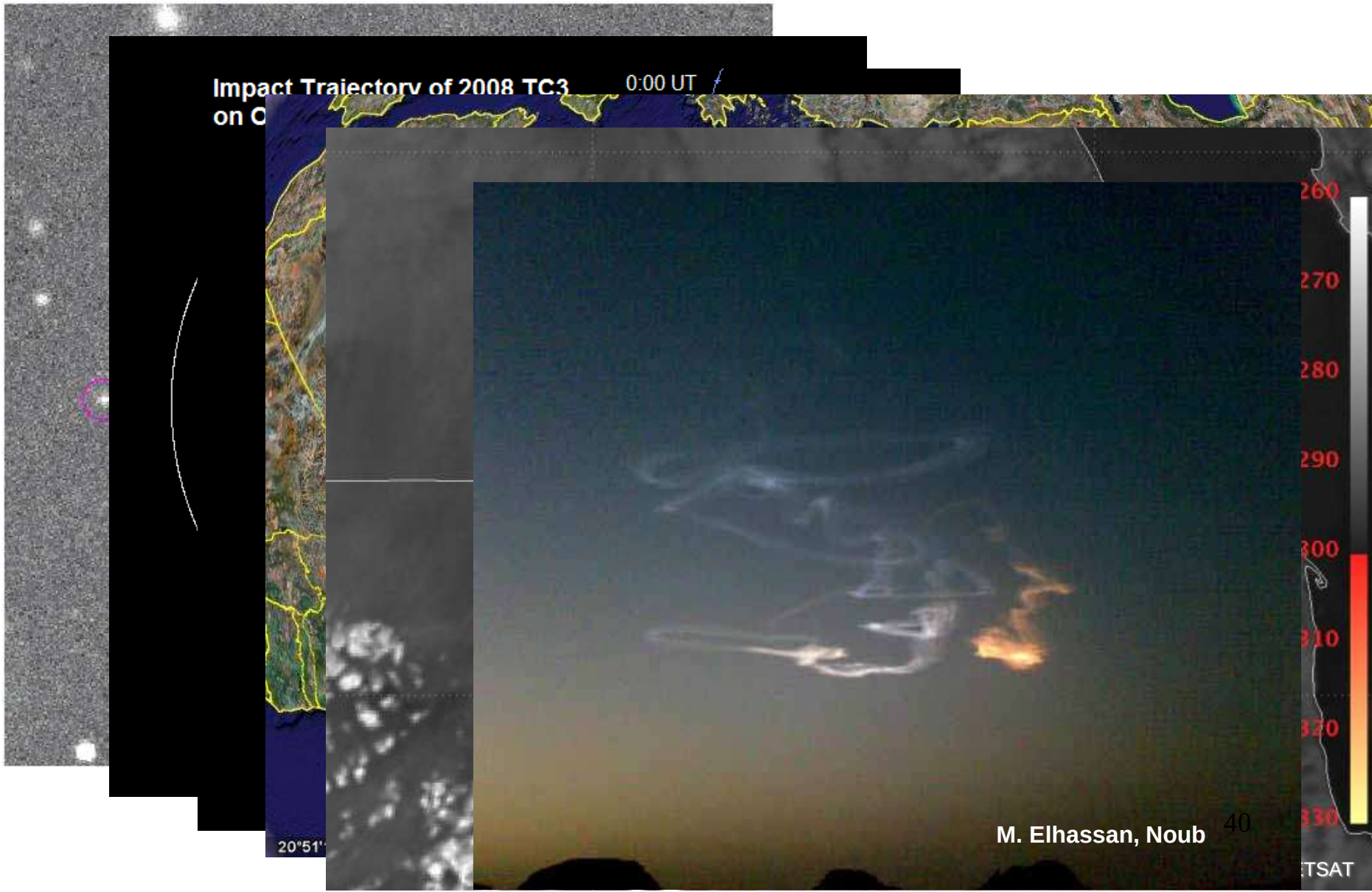

Recovery of 2008 TC3 Fragments

Courtesy of Dr Petrus Jenniskens, SETI Institute

Discovery of 1st fragment by University of Khartoum students led by Dr. Muawia Shaddad with data supplied by NASA

Enlarged image of TC3 fragment

What Could We Do About It?

Planetary Defense - Mitigating an Impact Event

- **At the very least, "civil defense"**
  - **Days to weeks warning, evacuate area to be affected**
- **Technology exists to provide years to decades warning**
  - **And change the hazardous objects orbit**
  - **Need to find them as early as possible**
- **With Sufficient warning, 3 methods of Orbit Deflection**

1. Kinetic Impactor - instant push

2. Gravity Tractor - slow pull

3. Nuclear device - surface material blowoff

United States Government Policy and Approach Regarding Planetary Defense

NASA Authorization Act of 2008

Title VIII – Near Earth Objects Signed Oct 2008

- ***SEC. 803. REQUESTS FOR INFORMATION.***
- *The Administrator shall issue requests for information on--*
- *(1) a low-cost space mission with the purpose of rendezvousing with, attaching a tracking device, and characterizing the Apophis asteroid; and*
- *(2) a medium-sized space mission with the purpose of detecting near-Earth objects equal to or greater than 140 meters in diameter.*
- ***SEC. 804. ESTABLISHMENT OF POLICY WITH RESPECT TO THREATS POSED BY NEAR-EARTH OBJECTS.***
- *Within 2 years after the date of enactment of this Act, the Director of the OSTP shall--*
- *(1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending near-Earth object threat, if near-term public safety is at risk; and*
- *(2) recommend a Federal agency or agencies to be responsible for--*
- *(A) protecting the United States from a near-Earth object that is expected to collide with Earth; and*
- *(B) implementing a deflection campaign, in consultation with international bodies, should one be necessary.*
- ***SEC. 805. PLANETARY RADAR CAPABILITY.***
- *The Administrator shall maintain a planetary radar that is comparable to the capability provided through the Deep Space Network Goldstone facility of NASA.*
- ***SEC. 806. ARECIBO OBSERVATORY.***
- *Congress reiterates its support for the use of the Arecibo Observatory for NASA-funded near-Earth object-related activities. The Administrator, using funds authorized in section 101(a)(1)(B), shall ensure the availability of the Arecibo Observatory's planetary radar to support these activities until the National Academies' review of NASA's approach for the survey and deflection of near-Earth objects, including a determination of the role of Arecibo, that was directed to be undertaken by the Fiscal Year 2008 Omnibus Appropriations Act, is completed.*
- ***SEC. 807. INTERNATIONAL RESOURCES.***
- *It is the sense of Congress that, since an estimated 25,000 asteroids of concern have yet to be discovered and monitored, the United States should seek to obtain commitments for cooperation from other nations with significant resources for contributing to a thorough and timely search for such objects and an identification of their characteristics.*

NASA Authorization Act of 2008

Title VIII – Near Earth Objects Signed Oct 2008

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Source

US Office of Science and Technology Policy (OSTP)
Letter to Congress dated 15 October, 2010*

Response to Section 804 of NASA Authorization Act of 2008

The Director of OSTP will:

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* http://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp-letter-neo-senate.pdf

Background

- US National Space Policy, June 28, 2010*

NASA shall: "Pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects."

* http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

- US President's FY2012 NASA Budget Request:

"The expanded Near-Earth Orbit Observation (NEOO) program [$20.4M] will improve and increase its efforts to detect Earth approaching asteroids and comets that may provide resources for our exploration of the inner solar system, or could become potential impact hazards to the Earth. It will also expand efforts to characterize their nature, both to better understand their composition and provide information for study of potential hazard mitigation techniques."

- US President's new plan for human space flight, announced April 15, 2010*, establishes the goal of conducting a human mission to an NEO by 2025

* http://www.whitehouse.gov/the-press-office/remarks-president-space-exploration-21st-century

NEO Threat Detection

Within US Government:

- NASA will coordinate NEO detection and threat information from all organizations within the NEO observation community
- NASA has instituted communications procedures, including direction with regard to public release of information
- NASA notification procedures are set into motion only after the necessary observations, analyses, and characterization efforts have taken place to determine that a space object indeed represents a credible threat
  - Depends on level of risk and urgency, may unfold for years after detection
  - Will entail various combinations of:
    - Increased monitoring
    - Cross-checks of potentially hazardous trajectories as needed
    - Accelerated observations and orbit determination if potential hazard is near term

NEO Threat Notification

Upon notification from NASA:

Of impending NEO Threat to United States territory:

- The Federal Emergency Management Agency (FEMA) takes lead to notify appropriate Federal, state and local authorities and emergency response institutions utilizing existing resources and mechanisms
  - When time/location of affected areas known, activate National Warning System
  - Analogous to large re-entering space debris and/or hurricane warning procedures
  - Post-impact event, analogous to other disaster emergency and relief efforts

Of NEO Threat beyond United States territory:

- Recognizing vital role US efforts lead in NEO detection activities, US Department of State facilitates international notifications in effort to minimize loss of human life and property
  - Bilaterally through diplomatic channels to potentially affected countries
  - To member nations of multilateral forums – UN entities (OOSA, COPUOS), NATO, etc
  - Post-impact event, convey offers of disaster relief and technical assistance

Potential NEO Mitigation/Deflection

- Essential first step is continued enhancement of efforts to detect NEOs
  - Identify potential impact hazards early
  - Provide as much advanced warning of impact threat to enable more mitigation options
- Potential roles and responsibilities for mitigation options is in early stage of development and not yet ready for implementation
  - Wide range of possible scenarios and challenges involved
  - Significantly more analysis and simulation needed to understand feasibility and effectiveness of several approaches, and technical assessment of current technologies
- NASA to take lead to conduct foundational analysis and simulation, assessment of applicable technologies
  - Close coordination with DOD, FEMA, and other relevant departments and agencies
  - Possible emergency response exercises to be led by FEMA
  - Outreach to relevant private-sector stakeholders to leverage related work
  - Important to engage other nations and multilateral forums to explore opportunities for international cooperation, e.g. UNCOPUOS, European Union, ISECG

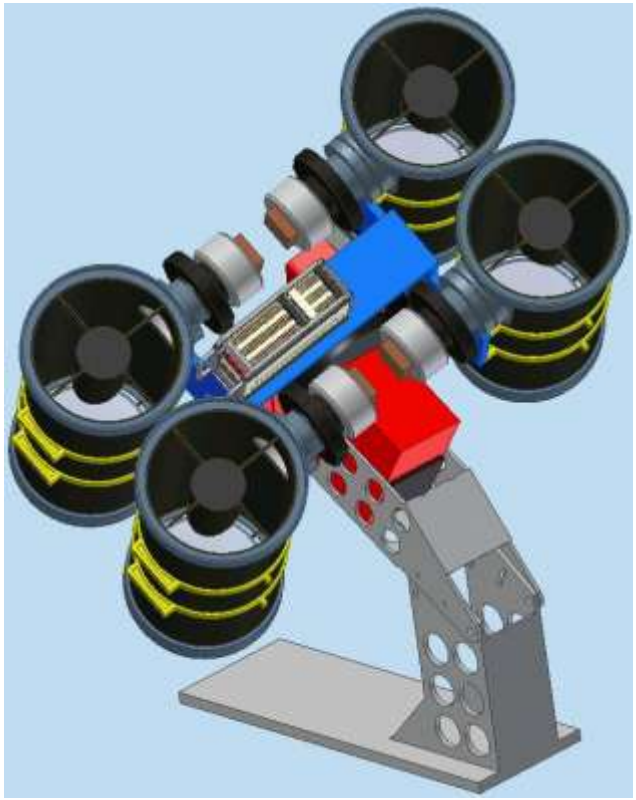
Future Plans for NASA NEO Program

Space SurveillanceTelescope

- **DARPA funded project**
- **Designed and built by MIT/LL**
  - **Same division as LINEAR**
- **Located Atom Peak, WSMR, NM**
- **3.6 meter primary mirror**
- **First Light was Feb 2011**
- **Started 1 year of checkout**
- **Eventual operations by AFSPC**
- **First of 3 to 4 worldwide sites**
- **Serendipitous detection of NEOs in background mode to space surveillance**

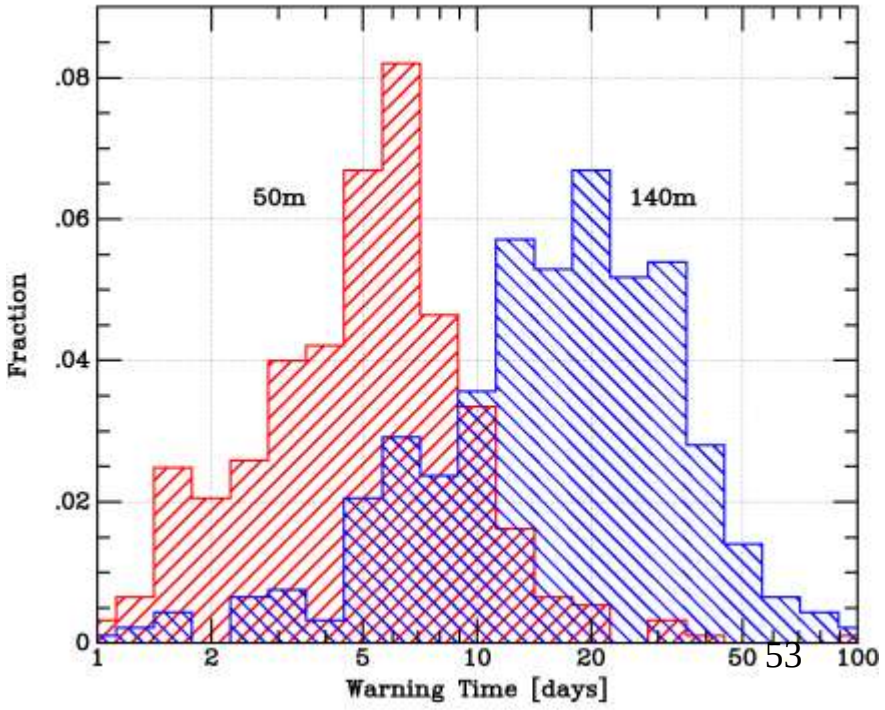
Near Term Impact Warning

Asteroid Terrestrial-impact Last Alert System –ATLAS*: **A**
project to patrol the entire night sky every night in search of incoming asteroids



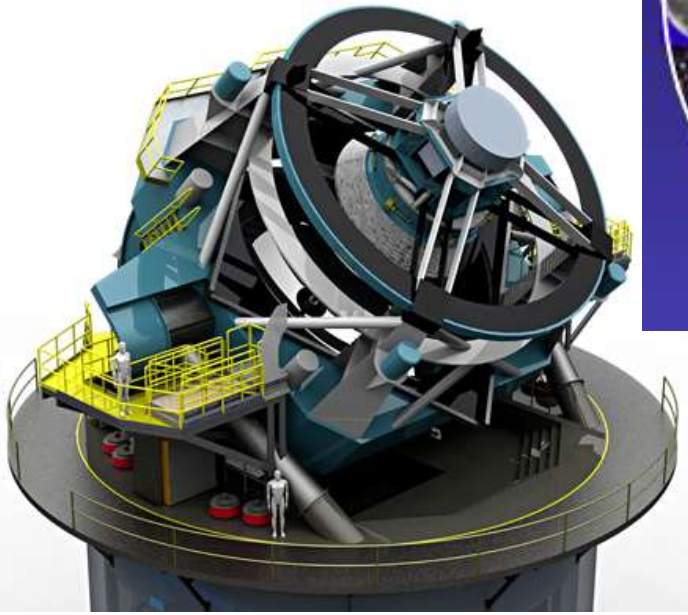
Proposed ATLAS telescope design

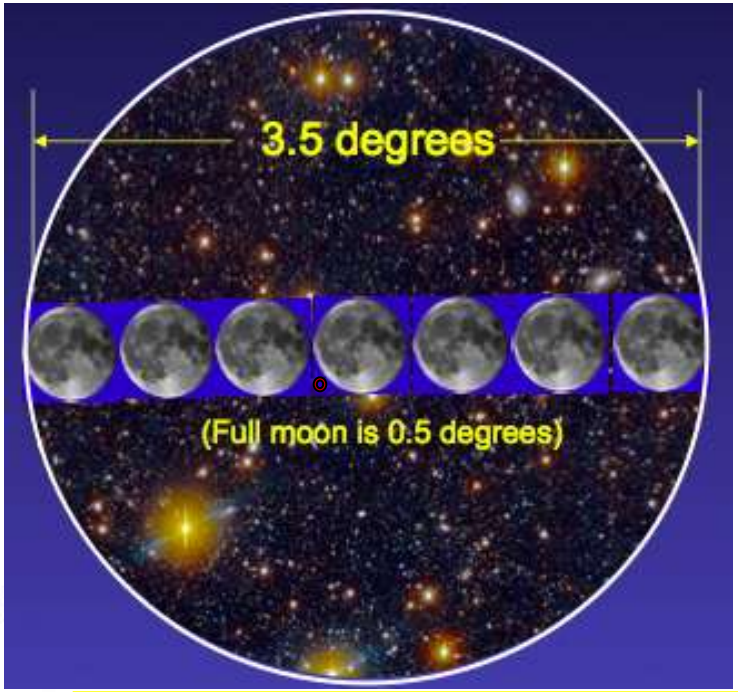
A geographically dispersed network (> 4 sites) of small coupled telescopes observing "shallow but wide" to provide more complete sky coverage for warning of near-term impact threats



*Courtesy University of Hawaii Institute for Astronomy

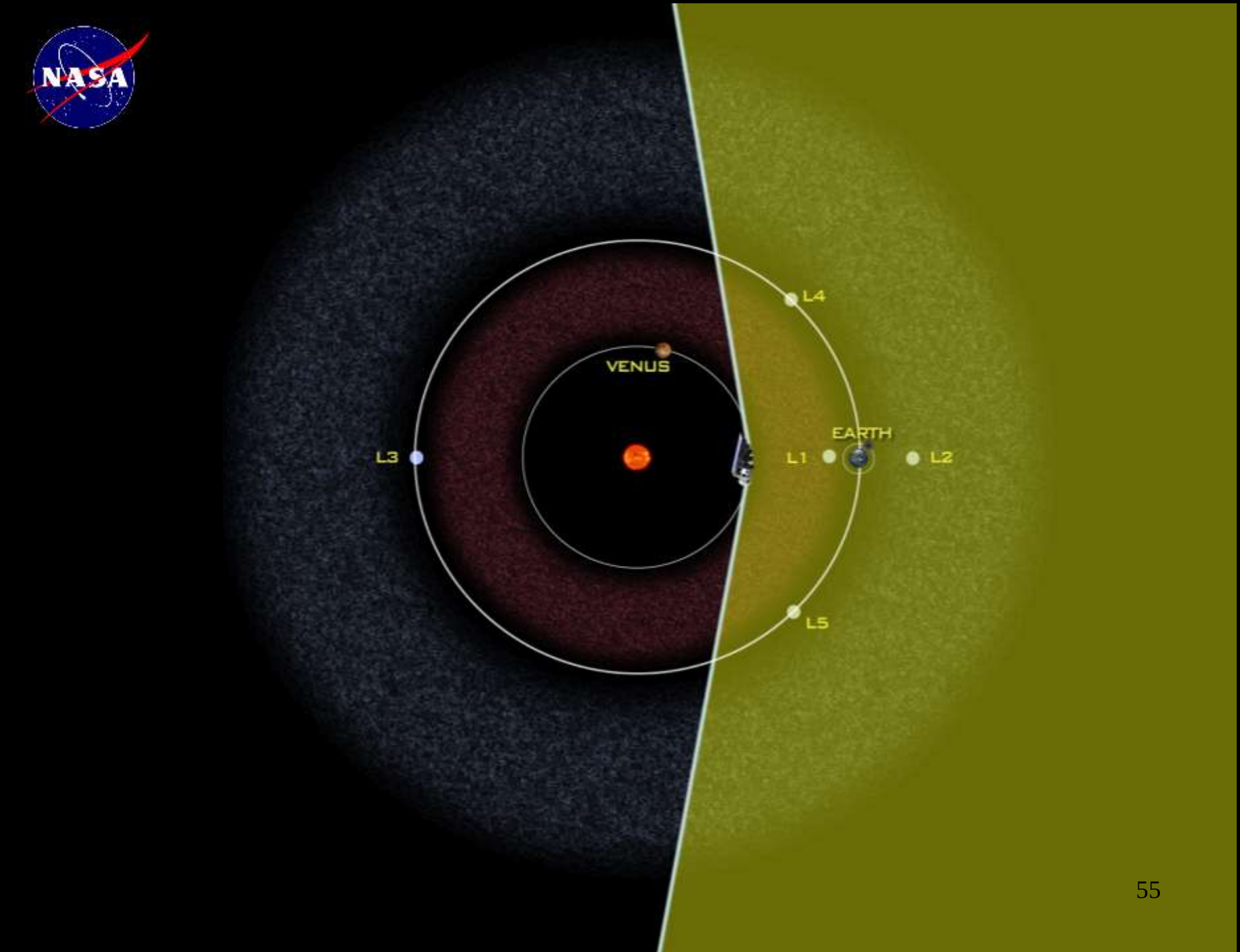
Large Synoptic Survey Telescope





- 6.4-m effective diameter
- 10 sq deg field of view
- ugrizy optical filters
- 18,000 square degrees ++
- 2x15s exposures + 2 more within 60 minutes
- Survey entire visible sky every 3-4 days in 2 filters for 10 years

Initial Operations 2019?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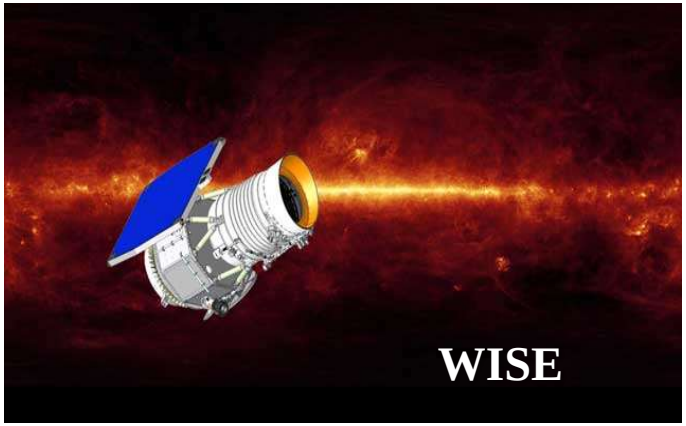
Space-based *"NEOStar"* Concept



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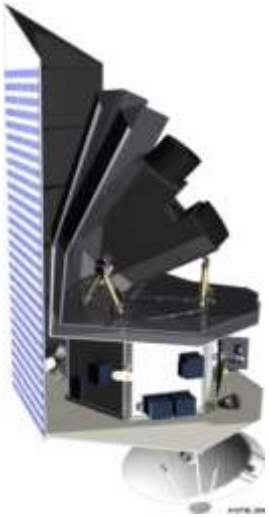
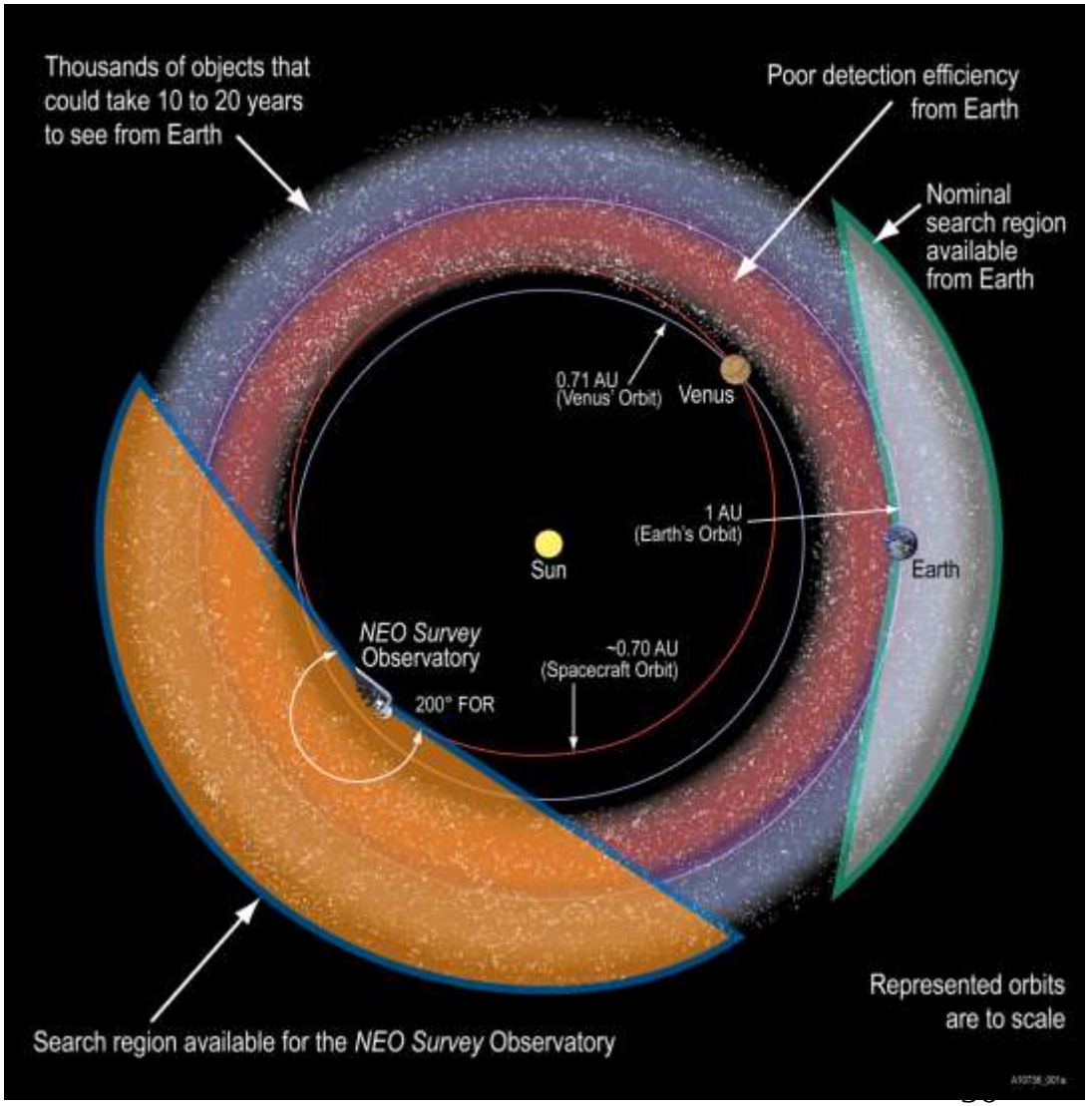
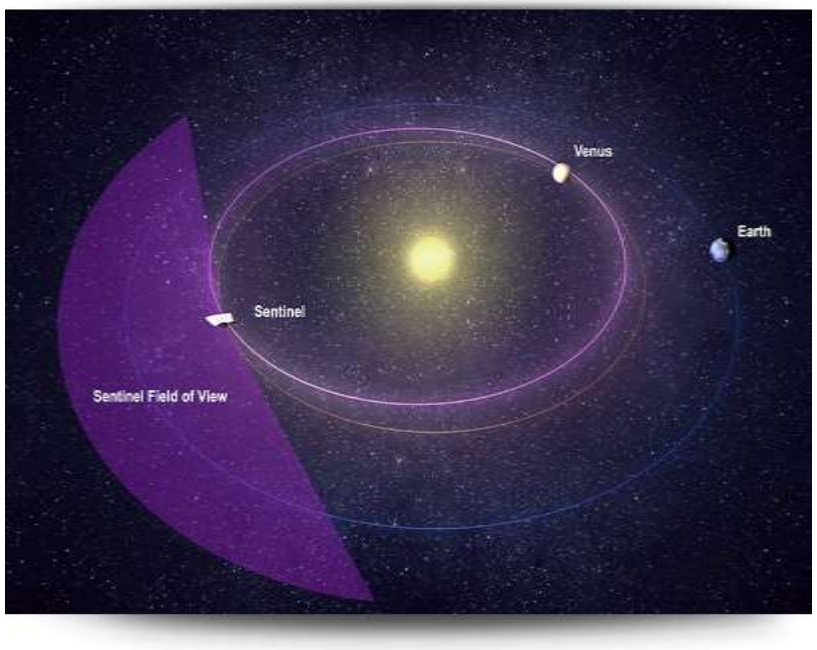


"NEOStar"



B612 *"Sentinel"* Project



NASA has signed a Space Act Agreement (SAA) to support B612 Project Sentinel

- Established NASA Technical Consulting Team (NTCT)
- Supported B612 Project Concept and Integration Review (PCIR)
- NTCT members will also support Sentinel Operations and Data Analysis (SODA) Working Group
- SAA Schedule/Milestones:

Sentinel contract start date	Sept. 2012
Preliminary Design Review	Sept. 2013
Critical Design Review	June 2014
Launch	June 2016
Initial on-orbit data delivery	NLT launch +6 mos